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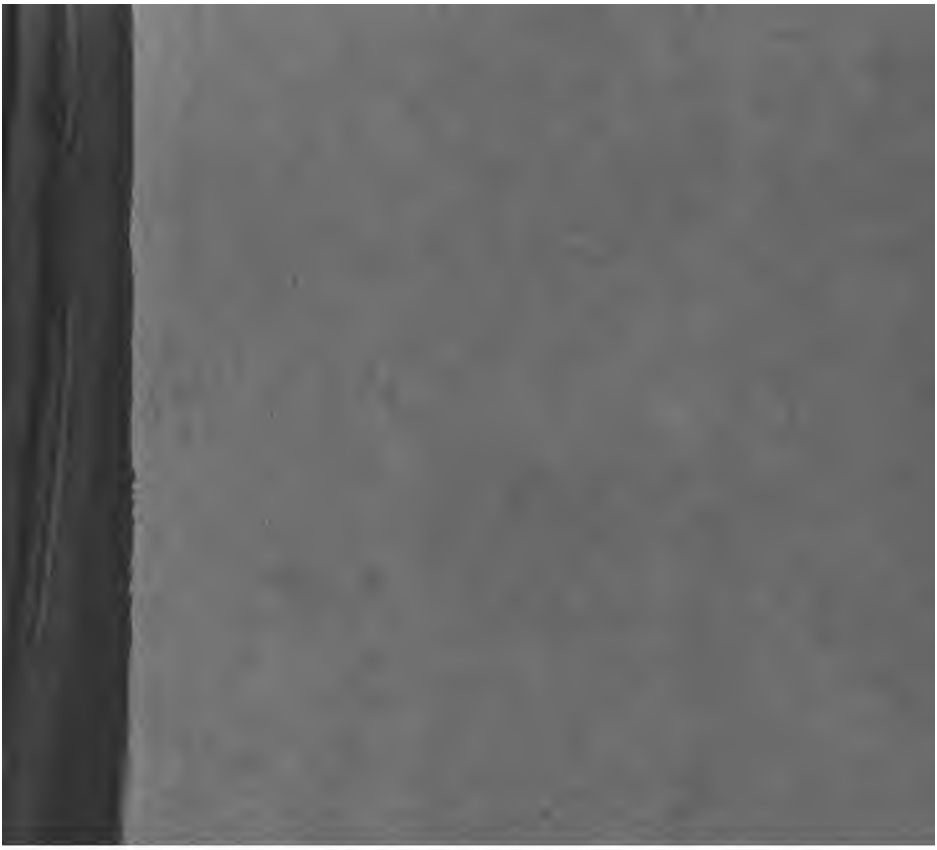

A TEXTBOOK

ON

PLUMBING, HEATING, AND VENTILATION

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

PRINCIPLES OF HEATING AND VENTILATION
STEAM HEATING
HOT-WATER HEATING
FURNACE HEATING
VENTILATION OF BUILDINGS

WITH PRACTICAL QUESTIONS AND EXAMPLES

1923

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PRINCIPLES OF HEATING AND VENTILATION.

HEAT.

1334. Heat *is a form of energy.* It is the effect of a motion of the molecules composing matter. It has already been stated that all matter is composed of molecules; now, these molecules are not in a state of rest, but are moving, or vibrating, back and forth with a greater or less velocity, and it is this movement of the molecules that causes the sensations of warmth or cold. If the motion is slow, the body appears cold to the touch; when the vibrations are rapid, the body becomes warm or hot.

1335. It has been shown that a body in motion possesses kinetic energy, the amount of which is measured in foot-pounds by multiplying the weight of the body by the square of its velocity and dividing by 64.32. Since the molecules composing matter are in motion, they must possess kinetic energy, and we are justified, therefore, in saying that *heat is a form of energy.*

1336. Temperature is a term used to indicate how hot or cold a body is; i. e., to indicate the rate of vibration of the molecules of a body. A hot body has a high temperature; a cold body, a low temperature. When a body, as, for example, an iron bar, receives heat from any source, its temperature rises; on the other hand, when a body loses heat, its temperature falls.

The temperature is *not* a measure of the *quantity* of heat a body possesses. *Temperature* may be considered to be a measure of the velocity of the molecules of a body as they vibrate to and fro, while the *quantity of heat* may be

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considered to be the kinetic energy of the molecules composing the body. A small iron rod may be heated to whiteness and yet possess a very small quantity of heat. Its temperature is very high, which simply indicates that the molecules of the rod are vibrating with an extremely high velocity.

Temperature is measured by an instrument called the thermometer, which is so familiar as to scarcely need description. It consists of a thin glass tube, at one end of which is a bulb filled with mercury. Upon being heated the mercury expands in proportion to its temperature. Thermometers are graduated in different ways. In the Fahrenheit thermometer, which is generally used in this country, the point where the mercury stands when the instrument is placed in melting ice is marked 32°. The point indicated by the mercury when the thermometer is placed in water boiling in the open air at the level of the sea is marked 212°. The tube between these two points is divided into 180 equal parts called degrees.

1337. Effects of Heat.—Suppose we take a vessel filled with water. Let the vessel be a cylinder fitted with a piston, as shown in Fig. 524. The water is say at the freezing point, and the millions of molecules composing the water are moving to and fro, with a comparatively small velocity. Place the vessel in a fire or furnace. Heat is communicated to the molecules of water, and they begin to move faster and faster and faster. That is, their kinetic energy increases, and, if a thermometer were inserted in the vessel, it would be found that the temperature of the water rises. Consequently, one effect of heat is to raise the temperature of the body to which it is applied. But, after reaching a certain temperature, the molecules of the water not only move faster, but they move further from each

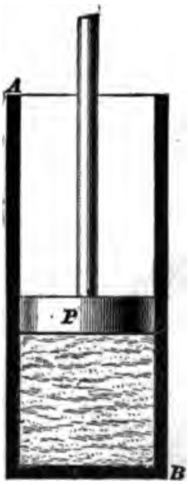

FIG. 524.

other and their paths are longer. It is plain that if the molecules are further apart than they were originally, the whole body of them must take up more space. In other words, after reaching a certain temperature, the water expands as heat is added. Hence, another effect of heat is to expand bodies to which it is applied. Common examples of the expansion of bodies by heat are seen in the expansion of the rails of a railway in summer, the lengthening of steam and hot-water pipes when they are heated, etc.

1338. The heat supplied to the vessel of water has so far done three things: 1. Raised the temperature of the water and thus increased the kinetic energy of the molecules. (Let the amount of heat expended for this purpose be denoted by S.) 2. A certain quantity of heat has been used in expanding the water; that is, in pushing its molecules further apart against the force of cohesion. (Denote the amount of heat so expended by I.) 3. Since the water expands, it must raise the piston P against the pressure of the atmosphere, and, consequently, more heat must be used to expand the water than would be required if there were no pressure on the upper side of the piston. (Call this extra quantity of heat, W.)

If we denote by Q the total heat given up to the vessel of water, we have

$$Q = S + I + W.$$

1339. Ordinarily, the greater part of the heat given to a body is spent in raising its temperature, and but little is used in expanding the body. That is, the quantity S is nearly equal to the quantity Q, while the quantities I and W are nearly nothing.

Suppose that the piston is removed from the cylinder of Fig. 524, and a thermometer inserted. As the vessel becomes more and more heated, the temperature indicated by the thermometer will rise until it reaches 212°. So far most of the heat has been used to raise the temperature of the water. But now, no matter how much heat is added to the water, the thermometer stands at 212° and can not be made to rise higher. This is the reason: When the temperature reaches 212° the molecules of water have been pushed so far apart that they are but slightly attracted to each other by the force of cohesion, and tend to separate. In other words, the water is changing to a gas (steam), and all of the heat is being used to effect this change. The temperature of the steam will remain at 212° until all the water is changed to steam; then, if more heat is applied, the temperature of the steam will begin to rise.

Suppose we take a block of ice at a temperature of say 14° and heat it. If a thermometer is placed in contact with the ice, its temperature will rise until it reaches 32° and will then remain stationary. As soon as this temperature is reached the ice begins to melt or change to water, and the heat, instead of raising the temperature further, is all used to effect this change of state. Here, then, is another effect produced by heat. It will change a solid to a liquid or a liquid to a gas.

1340. Latent heat.—The heat which is expended in changing a body from the solid to the liquid state or from the liquid to the gaseous state is called **latent heat.** The portion of the heat applied which raises the temperature, and which, therefore, affects the thermometer, is sometimes called **sensible heat.**

1341. Measurement of Heat.—Since heat is not a substance, it can not be measured directly in pounds or quarts; but, like force, it may be measured by the effects it produces. Suppose a certain quantity of heat raises the temperature of a pound of water from 52° to 53°. It will take the same quantity of heat to raise the temperature of a pound from 53° to 54°, and it will take double the quantity to raise the temperature of the pound of water from 52° to 54° that it took to raise the temperature from 52° to 53°. The unit quantity of heat is the quantity required to raise the temperature of a pound of water from 62° to 63°. This unit is called the **British thermal unit,** or B. T. U.

HEAT PROPAGATION.

1342. Heat may be transmitted by *radiation*, by *conduction*, and by *convection*.

RADIATION.

1343. The tendency of heat is to pass away from a warm body instantaneously, and with equal energy in all directions. This manner of transit is called **radiation.** Strictly speaking, all heat is *radiant heat*, because it invariably proceeds by radiation when it is not obstructed or retarded by the medium or material through which it passes. All known materials retard the transmission of heat to a greater or less degree. Thus, dry air permits heat to pass through it with very little obstruction, but wood offers great resistance.

The transmission of heat through a body will not affect its temperature unless the transmission is impeded to some extent. The heat which is thus intercepted may be wholly absorbed by the body or a part of it may be reflected. The temperature of the body will be raised only by that part of the heat which is absorbed.

Thus, if a sheet of clear ice be exposed to heat, a certain amount will pass through it, the greater part, however, being absorbed, causing the ice to melt. If a person attempts to warm himself at a blazing fire, out of doors on a cold day, he may be scorched on one side by the radiant heat of the fire at the same time that he is almost frozen on the other side by the cold air which surrounds him. The air which is between him and the fire thus permits the heat to pass through it without much loss.

1344. The law which governs the *intensity* of radiant heat is as follows:

The temperature will be inversely proportional to the square of the distance from the source of heat

Thus, the heat which is received upon a surface one foot square at a distance of 5 feet will diverge and cover a space of twice that width and height, having 4 times the area at a distance of 10 feet; the heat, being spread over four times as much surface, can have only one-fourth the intensity.

EXAMPLE.—The temperature of a certain body at a distance of 5 feet from the source is 300°; what will the temperature be at a distance of 10 feet?

SOLUTION.—Applying the law stated above,

$$300 : x :: 10^2 : 5^2, \text{ or } x = 75^\circ. \quad \text{Ans.}$$

1345. Diathermancy.—Some substances permit radiant heat to pass through them as readily as light passes through glass, while others obstruct it totally. The property of a body by virtue of which heat is enabled to pass through it is called **diathermancy.** A knowledge of the diathermic properties of metals and other substances is valuable, for means may then be devised for protecting woodwork from overheating by fire, etc. Dry air, oxygen, nitrogen, and hydrogen are almost perfectly diathermanous. A perfect vacuum also passes heat without measurable obstruction. The watery vapor which forms a part of the atmosphere greatly obstructs the passage of radiant heat, and much of the non-conducting power which is popularly ascribed to air is really due to the vapor and dust which it contains.

1346. The following table shows the percentage of radiant heat which will pass through the substances named:

TABLE 47.

	Per Cent.
Ordinary window glass, .07 inch thick	50 to 67
Colored window glass, .07 inch thick, Violet	45 to 53
Colored window glass, .07 inch thick, Blue	20 to 42
Colored window glass, .07 inch thick, Green	23 to 26
Colored window glass, .07 inch thick, Yellow	40 to 44
Colored window glass, .07 inch thick, Red	51 to 53
Rock salt, clear, 2½ inches thick	92
Pure water, layer ⅜ inch thick	11
Pure alcohol, layer ⅜ inch thick	15
Pure sulphuric acid, layer ⅜ inch thick	17
Spirits of turpentine, layer ⅜ inch thick	31
Nut oil, layer ⅜ inch thick	31
Olive oil, layer ⅜ inch thick	30
Colza oil, layer ⅜ inch thick	30

These substances are supposed to be placed as a screen between the source of heat and the body to be heated. but not in contact with either. There should be a free circulation of air around the screen on both sides.

If two screens of the same substance are used, one behind the other, the second screen will pass a much larger percentage of the heat which falls upon it than the first one. A third screen will in many cases pass nearly all of the heat which passes the second screen.

1347. Reflection.—Heat may be reflected, dispersed, or concentrated by means of mirrors or lenses, in the same manner as light. The following table shows the reflecting power of various substances when the heat rays fall upon them at an angle of 90°, the power being expressed as a percentage of the total radiant heat received:

TABLE 48.

REFLECTING POWER.

	Per Cent.		Per Cent.
Polished Silver	97	Polished Zinc	81
Polished Brass	93	Polished Iron	77
Polished Copper	93	Bright Tin	85
Polished Steel	83	Glass	10

Thus, polished silver will reflect 97 per cent. and will absorb 3 per cent. of the radiant heat falling upon it. The metal will slowly become warmed by the heat absorbed.

Glass reflects only 10 per cent., but, being diathermanous, a large part of the remaining 90 per cent. will pass through, and the percentage of heat which will be absorbed by it will be comparatively small. Consequently, its temperature will rise slowly.

The percentage of reflection varies somewhat with the angle at which the rays of heat impinge upon the reflecting surface, becoming greater as the angle becomes less than 90°. The increase, in the case of glass, is considerable.

Heat may be concentrated by means of mirrors, if we arrange several of them so as to converge the reflected rays at one point. The heat of the sun has been successfully applied to the generation of power by this means. The common burning glass is an example of the concentration of heat by means of a lens. The temperature of the concentrated rays will be equal to the total heat of the rays thus brought together.

CONDUCTION.

1348. When the transmission of heat through any certain substance requires a measurable amount of time, the manner of transmission is called **conduction.** Thus, it becomes clear that the distinction between radiation and conduction has regard to the *rapidity* of the transmission; radiation being *instantaneous* transmission, and conduction being merely *retarded* transmission. All known substances will conduct heat to a measurable extent, but the rapidity of the conduction varies greatly in different materials. Thus, substances are classed as **good conductors,** or **bad conductors,** according to the rapidity with which they will conduct heat.

1349. The transmission of heat through a body may be divided into three phases:

1. The absorption of the heat at the receiving surface. 2. The conduction through the interior substance of the body. 3. The emission from the radiating surface.

All metals will conduct heat internally much faster than they can either absorb it at, or emit it from, their surfaces. It will be seen, therefore, that a knowledge of their actual *conducting* power is not so valuable or essential in the arts of heating and ventilation as a knowledge of their *transmitting* power.

1350. The law which governs the distribution of heat by conduction is as follows:

All bodies within a given enclosure tend to come to an equal *temperature; and the heat within any particular body will tend to diffuse uniformly throughout its whole extent.*

If one or more of the bodies have a higher temperature than the others, an interchange of heat will take place until all are equally heated.

1351. The following table shows the relative conducting powers of various materials, silver being taken as the standard:

TABLE 49.

Silver	100	Cast Iron	17
Copper	77	Zinc	20
Brass	33	Tin	15
Steel	12	Lead	8.5

These figures represent only the relative rapidity of the passage of heat from one point to another within the same body, and do not truthfully represent the capacity of the body to receive and deliver heat from or to other bodies.

The rate at which heat may be absorbed at or emitted from the surface of a body depends upon the nature of the material, and very largely upon the condition of the surface, that is, whether it be rough, smooth, or polished.

When heat passes from a dense substance to a lighter one, or the reverse, the transmission is considerably retarded, and the condition of the surface through which it passes determines the rapidity of the passage.

The absorptive and emissive powers of any particular substance are usually equal. A surface of freshly deposited lampblack is found by experiment to be one of the best to absorb or emit heat, and it is, therefore, taken as a standard of comparison.

1352. The relative amount of heat absorbed or emitted by the surfaces of various substances is shown in the following table:

TABLE 50.

Lampblack, dry	100	Steel	17
White Lead, dry powder	100	Polished Brass	7
Paper	98	Polished Copper	7
Glass	90	Polished Silver	3

The table shows that the color does not affect the heat-absorbing capacity of the material, lampblack and white lead being equal in that respect.

The actual rate of emission of heat from various kinds of surfaces and materials is more fully considered in Arts. **1554** to **1558.**

CONVECTION.

1353. If there is any difference in the condition of the various layers of a body in weight, electric tension, or chemical condition, they will move about until all the particles have acquired the same condition. The minute motion of each particle is called **convection,** and the general movement of the mass upon itself is called **circulation.**

1354. Convection currents are caused in many ways; thus, if a lump of sugar or of salt is partially dissolved in water, the film of water which is in contact with the lump will be denser than the surrounding water, and will sink towards the bottom of the vessel. If a lump of ice is dissolved in water, convection currents will be set in motion in a similar manner, although there may be no apparent difference in temperature between them. The convection, which is caused by the application of heat to the lower layers of a liquid, is due to the expansion of these heated layers, which thus become lighter than the cold ones, and float upwards because of their buoyancy. If the heat is applied to the surface of the liquid, but little convection will occur; the motion being confined to the upper layers of the liquid, the heat will be conducted downwards through the liquid without motion, in the same manner as though it were a solid substance.

1355. The diffusion of heat throughout a liquid may be greatly facilitated by convection if the heat is applied to the lower part of the mass, but not otherwise. Each heated particle when in motion comes into successive contact with great numbers of colder particles, to which its heat is conducted by actual contact. If the particles did not move (but remained stationary, as in a solid substance) or if there were no convection, it could impart its heat only to the few surrounding particles which touched it. By *particle* is meant a very minute portion of matter composed of a group of molecules.

Air and other gases which are almost perfectly diathermanous must be heated mainly by convection. The heat may be applied with greatest effect at the bottom of the enclosure. In many cases the heat will radiate from the hot surface and warm the opposite side of the chamber, thus increasing the extent of the heating surface and expediting the operation.

DYNAMICAL THEORY OF HEAT.

1356. Before going any further, it will be convenient to explain the view now generally taken as to the mode in which heat is propagated. On this subject, it is stated in Ganot's Physics: "A hot body is one whose molecules are in a state of vibration. The higher the temperature of a body, the more rapid are these vibrations, and a diminution in temperature is but a diminished rapidity of the vibrations of the molecules. The propagation of heat through a bar is due to a gradual communication of this vibratory motion from the heated part to the rest of the bar. A good conductor is one which readily takes up and transmits the vibratory motion from molecule to molecule, while a bad conductor is one which takes up and transmits the motion with difficulty. But even through the best of the conductors the propagation of this motion is comparatively slow. How, then, can be explained the instantaneous perception of heat when a screen is removed from a fire or when a cloud drifts from the face of the sun? In this case, the heat passes from one body to another without affecting the temperature of the medium which transmits it. In order to explain these phenomena, it is imagined that all space, the space between the planets and the stars, as well as the interstices in the hardest crystal—in short, matter of any kind—is permeated by a medium having the properties of matter of infinite tenuity, called *ether*. The molecules of a heated body, being in a state of intensely rapid vibration, communicate their motion to the ether around them, throwing it into a system of waves which travel through space and pass from one body to another with the velocity of light. When the undulations of the ether reach a given body, the motion is given up to the molecules of that body, which, in their turn, begin to vibrate; that is, the body becomes heated. This motion of the waves through the ether is termed radiation, and what is called a ray of heat is merely a series of waves moving in a given direction."

EXPANSION OF BODIES BY HEAT.

1357. If a body absorbs heat, its volume will be changed correspondingly. Nearly all bodies expand when heated; a few substances, however, contract, but these exceptions are of no practical importance.

1358. Air and all other gases expand *uniformly* for each degree of rise in temperature above zero. Air, at zero F., will expand $\frac{1}{460}$ of its volume for each degree of rise in temperature. Thus, air at 70° will have a volume equal to $1 + \frac{70}{460}$, or $\frac{530}{460}$ of its volume at zero, if its tension remains unchanged. By *tension* is meant the pressure which a gas exerts on the vessel which confines it.

The rule for computing the increase in the *volume of air* for different temperatures is given in Art. **1424.**

1359. The *volume of water* does not increase at the same rate as the temperature; therefore, the expansion has been determined by experiment, and the results are given in the following table:

TABLE 51.

EXPANSION AND WEIGHT OF PURE WATER FROM 32° TO 390° F.

1	2	3	4	1	2	3	4
Temperature.	Comparative Volume.	Comparative Density.	Weight of 1 Cu. Ft.	Temperature.	Comparative Volume.	Comparative Density.	Weight of 1 Cu. Ft.
Fahr.	Water at 32° = 1.	Water at 32° = 1.	Pounds.	Fahr.	Water at 32° = 1.	Water at 32° = 1.	Pounds.
32.0°	1.00000	1.00000	62.418	135.0°	1.01539	0.98484	61.472
35.0	0.99993	1.00007	62.422	140.0	1.01690	0.98339	61.381
39.1	0.99989	1.00011	62.425	145.0	1.01839	0.98194	61.291
40.0	0.99989	1.00011	62.425	150.0	1.01989	0.98050	61.201
45.0	0.99993	1.00007	62.422	155.0	1.02164	0.97882	61.096
46.0	1.00000	1.00000	62.418	160.0	1.02340	0.97714	60.991
50.0	1.00015	0.99985	62.409	165.0	1.02589	0.97477	60.843
52.3	1.00029	0.99971	62.400	170.0	1.02690	0.97380	60.783
55.0	1.00038	0.99961	62.394	175.0	1.02906	0.97193	60.665
60.0	1.00074	0.99926	62.372	180.0	1.03100	0.97006	60.548
62.0	1.00101	0.99899	62.355	185.0	1.03300	0.96828	60.430
65.0	1.00119	0.99881	62.344	190.0	1.03500	0.96632	60.314
70.0	1.00160	0.99832	62.313	195.0	1.03700	0.96440	60.198
75.0	1.00239	0.99771	62.275	200.0	1.03889	0.96256	60.081
80.0	1.00299	0.99702	62.240	205.0	1.04140	0.96020	59.930
85.0	1.00379	0.99622	62.182	210.0	1.04340	0.95840	59.820
90.0	1.00459	0.99543	62.133	212.0	1.04440	0.95750	59.760
95.0	1.00554	0.99449	62.074	230.0	1.05290	0.94990	59.360
100.0	1.00639	0.99365	62.022	250.0	1.06280	0.94110	58.750
105.0	1.00739	0.99260	61.960	270.0	1.07270	0.93230	58.180
110.0	1.00889	0.99119	61.868	290.0	1.08380	0.92270	57.590
115.0	1.00989	0.99021	61.807	298.0	1.08990	0.91750	57.270
120.0	1.01139	0.98874	61.715	338.0	1.11180	0.89940	56.140
125.0	1.01239	0.98808	61.654	366.0	1.13010	0.88500	55.290
130.0	1.01390	0.98630	61.563	390.0	1.14440	0.87380	54.540

1360. The increase in volume caused by heating water may be computed by the following

Rule.—*Multiply the volume at the lower temperature by the difference in the comparative volumes at the original and final temperatures.*

Example.—A heating apparatus contains 300 cubic feet of water at 60°; how much will the water expand if the temperature is raised to 230°?

Solution.—The comparative volumes of the water are shown by the table to be as follows:

$$\begin{array}{lr} & \text{At } 230^\circ = 1.05290 \\ & \text{At } \;\;60^\circ = \underline{1.00074} \\ \text{The difference is} & .05216 \end{array}$$

Multiplying the original volume by this difference, we have 300 × .05216 = 15.648 cubic feet. Ans.

Water is practically incompressible, and it expands with as much force as ordinary metals. When water is heated or cooled the vessel or pipes which contain it expand or contract also, but in a less degree.

1361. The linear expansion, or extension, of metals for one degree rise of temperature is given in the following table:

TABLE 52.

EXPANSION OF MATERIALS.

Material.	Increase of Length in 1 Foot for an Increase in Temperature of 1° F.	Material.	Increase of Length in 1 Foot for an Increase of Temperature of 1° F.
	Inches.		Inches.
Cast Iron	.0000740	Lead	.0001900
Wrought Iron	.0000823	Tin	.0001692
Steel Tubes	.0000719	Glass	.0000550
Brass	.0001244	Brick	.0000144
Copper	.0001146	Firebrick	.0000333
Zinc	.0001961	Marble	.0000566

1362. The amount of the expansion or contraction of a bar or pipe of a given length, which will be caused by any given change in its temperature, may be found as follows:

Rule.—*Multiply the length in feet by the number of degrees of change in temperature. Multiply this product by the coefficient given in the above table for the material employed. The result will be the change in length in inches.*

EXAMPLE.—How much will a steel tube 14 ft. long expand, if its temperature is raised 80° ?

SOLUTION.—From Table 52, the coefficient of linear expansion per unit of length for a rise in temperature of 1° is found to be .0000719 for steel tubes. Hence, using the rule last given, 14 × 80 × .0000719 = .080528 in. Ans.

1363. The expansion of wood by heat is so small that it is usually disregarded.

If metallic bodies are heated above a certain degree (varying for different metals), and the heat is continued for any considerable length of time, the metal will become permanently elongated, and upon cooling will not contract to its original dimensions. The metal is then said to be "swelled." Thus, grate bars in a furnace, or pipes which are exposed to intense heat, will increase considerably in length during long use. The strength of the metal deteriorates at the same time. Thus, plates or parts of furnaces which are unduly heated will swell permanently, and bulge or crack the adjoining parts.

SPECIFIC HEAT.

1364. One B. T. U. will raise the temperature of a pound of water from 62° to 63°. The question arises, will the B. T. U. raise a pound of any other substance, say mercury or iron, through the same range of temperature? Suppose two iron balls of the same weight are heated in boiling water. They will each have a temperature of 212°, and being of the same weight they must possess the same quantity of heat. Plunge one of the balls into a vessel containing say 10 pounds of water, and the other into a vessel containing 10 pounds of mercury, both mercury and water being at a temperature of 62°. Suppose the size of the balls is such that the temperature of the water is raised from 62° to 64° by the heat contained within the ball. Then, it will be found that the mercury will be raised from 62° to 122°. That is, the same amount of heat that raises 10 pounds of water 2° raises 10 lb. of mercury 60°, or through a range of temperature 30 times as great. It is plain, therefore, that to raise a pound of mercury from 62° to 63° requires $\frac{1}{30}$ the heat necessary to raise a pound of water from 62° to 63°. Hence, we say the *specific heat* of the mercury is $\frac{1}{30}$, or .0333.

1365. *The* **specific heat** *of a body is the ratio between the quantity of heat required to warm that body one degree and the quantity of heat required to warm an equal weight of water one degree.*

EXAMPLE 1.—It is found that to raise the temperature of 20 lb. of iron from 62° to 63° requires 2.276 B. T. U. What is the specific heat of iron?

SOLUTION.—To raise 20 lb. of water from 62° to 63° requires 20 B. T. U. The specific heat of the iron is, according to the above definition, the ratio between the quantities of heat required to warm the iron and the water, respectively, through one degree, that is, it is the ratio $2.276 : 20 = 2.276 \div 20 = .1138$. Ans.

EXAMPLE 2.—The specific heat of silver is .057. How many B. T. U. are required to raise the temperature of 22 lb. of silver from 50° to 60°?

SOLUTION.—To raise the temperature of a pound of water one degree requires one B. T. U. Since the specific heat of silver is .057, only .057 B. T. U. is required to raise one pound of silver one degree. Hence, to raise 22 pounds of silver 10 degrees must require $.057 \times 22 \times 10 = 12.54$ B. T. U. Ans.

Rule.—*To find the number of B. T. U. required to raise the temperature of a body a given number of degrees, multiply the specific heat of the body by its weight in pounds and by the number of degrees.*

Denote the number of B. T. U. required by U; the specific heat by c; the weight by W, and let t and t_1 be the temperatures before and after the heat is applied, respectively.

Then, $U = c\ W(t_1 - t)$.

1366. The specific heat of various substances is shown by the following table:

TABLE 53

SOLIDS.

Copper	0.0951	Cast Iron	0.1298
Gold	0.0324	Lead	0.0314
Wrought Iron	0.1138	Platinum	0.0324
Steel (soft)	0.1165	Silver	0.0570
Steel (hard)	0.1175	Tin	0.0562
Zinc	0.0956	Ice	0.5040
Brass	0.0939	Sulphur	0.2026
Glass	0.1937	Charcoal	0.2410

LIQUIDS.

Water at 62°	1.0000	Lead (melted)	0.0402
Alcohol	0.7000	Sulphur (melted)	0.2340
Mercury	0.0333	Tin (melted)	0.0637
Benzine	0.4500	Sulphuric Acid	0.3350
Glycerine	0.5550	Oil of Turpentine	0.4260

GASES.

Air	0.23751	Carbonic Oxide	0.2479
Oxygen	0.21751	Carbonic Acid	0.2170
Nitrogen	0.24380	Olefiant Gas	0.4040
Hydrogen	3.40900		

The table shows that the amount of heat which would be required to raise the temperature of 1 pound of water would be sufficient to heat to an equal degree about 8 pounds of cast iron, or 30 pounds of mercury, or 4 pounds of air, which is about 54 cubic feet.

It appears, also, that the heat required to raise the temperature of hydrogen gas is about 3½ times as much as for an equal weight of water. The specific heats for gases given in the above table are true only when the pressure remains constant.

1367. Temperature of Mixtures.—It is often desirable to calculate the final temperature of a mixture of different substances at different temperatures. The following law is to be observed in such cases: *The quantity of heat in a mixture is the same as the quantity of heat contained in the substances before being combined.* If two substances of different temperatures are placed together, they both finally attain the same temperature; the heat lost by the one in coming from a higher to a lower temperature is gained by the other in passing from a lower to a higher temperature.

Rule.—*To find the temperature of a mixture of several substances, multiply together the weight, specific heat, and temperature of each substance separately, and add the products. Next multiply together the weight and specific heat of each of the substances separately, and add these products. Divide the former sum by the latter. The result will be the temperature of the mixture.*

EXAMPLE.—A copper vessel weighing 2 lb. is partly filled with 7.8 lb. of water, both water and vessel having a temperature of 80°. A piece of wrought iron weighing 3 lb. 4 oz. and having a temperature of 780° is dropped into this water. What is the final temperature of the mixture?

SOLUTION.—Applying the rule last given, the product of the weight, specific heat, and temperature of the copper is $2 \times .0951 \times 80 = 15.216$; of the water, $7.8 \times 1 \times 80 = 624$; of the iron, $3.25 \times 1138 \times 780 = 288.483$, and the sum is $15.216 + 624 + 288.483 = 927.699$. The product of the weight and specific heat of the copper is $2 \times .0951 = .1902$; of the water, $7.8 \times 1 = 7.8$; of the iron, $3.25 \times .1138 = .36985$, and the sum is $.1902 + 7.8 + .36985 = 8.36005$, say 8.36. Then, the temperature of the mixture is $927.699 \div 8.36 = 110.97°$. Ans.

Example.—A body of air weighing 25 lb. and having a temperature of 32° is to be heated by means of 10 lb. of water having a temperature of 200°; what temperature will the air attain, supposing no heat to be lost and that the pressure remains constant?

Solution.—Applying the preceding rule, $25 \times .23751 \times 32 = 190.008$; $10 \times 1 \times 200 = 2{,}000$; $190.008 + 2{,}000 = 2{,}190.008$.
$25 \times .23751 = 5.93775$; $10 \times 1 = 10$; $5.93775 + 10 = 15.93775$, and $2{,}190.008 \div 15.93775 = 137.4°$. Ans.

1368. It sometimes happens, as in the following example, that it is desirable to find the temperature of a body by mixing it with a certain amount of water instead of using a thermometer. In such cases the temperature of the mixture is measured and the following rule applied:

Rule.—(*a*) *Multiply together the weight and specific heat of each substance separately, add the products, and multiply the sum by the temperature of the mixture.* (*b*) *Then, multiply together the weight, specific heat, and temperature of each substance separately, except the one whose temperature is to be found; add the products and subtract the sum from the result obtained in* (*a*). (*c*) *Divide the result obtained in* (*b*) *by the product of the weight and specific heat of the substance whose temperature is to be found, and the result will be the temperature of the body.*

Example.—A wrought-iron ball weighing 1 lb. is placed in a heating furnace; when it has attained the temperature of the furnace, it is taken out and placed in a copper vessel weighing ½ lb., which contains exactly 2 lb. of water at a temperature of 75°. Assuming that no heat escapes in steam, and that the temperature of the ball, water, and vessel after mixing is 156°, what is the temperature of the furnace?

Solution.—Applying the rule just given, we have for (*a*), $1 \times .1138 = .1138$; $.5 \times .0951 = .04755$; $2 \times 1 = 2$; $.1138 + .04755 + 2 = 2.16135$, and $2.16135 \times 156 = 337.1706$. For (*b*), $.5 \times .0951 \times 75 = 3.56625$; $2 \times 1 \times 75 = 150$; $3.56625 + 150 = 153.56625$, and $337.1706 - 153.56625 = 183.60435$. For (*c*), $1 \times .1138 = .1138$, and $183.60435 \div .1138 = 1{,}613.40°$. Ans.

LATENT HEAT.

1369. In changing a solid body to a liquid, either by melting or by dissolving it, or in changing a liquid to vapor or gas, a large amount of heat may be applied without changing the temperature. Thus, a pound of ice at 32° will absorb 142.65 heat units in changing to water having the same temperature. Again, the pound of water thus produced may be heated to the boiling point 212° by the addition of 180.531 heat units. But in order to convert the water at 212° into steam at the same temperature, 966.069 heat units must be added. Thus, a pound of steam at 212° contains $966.069 + 180.531 + 142.65 = 1{,}289.25$ heat units more than a pound of ice at 32°, although the difference in temperature is only 180°.

The heat which is thus absorbed in the processes of melting or vaporization is called **latent heat.**

1370. The temperature at which a body changes from a solid to a liquid state is called the **temperature of fusion**; and the number of B. T. U. required to effect this change in a body weighing one pound is called the **latent heat of fusion.** The temperature at which a body changes from a liquid state to a vapor (gas) is called the **temperature of vaporization**; and the heat required to effect this change in one pound of the liquid is called the **latent heat of vaporization.**

When a vapor changes back to a liquid, it is said to **condense**; and when a liquid changes back to a solid, it is said to **freeze**; in either case, an amount of heat equal to the latent heat of vaporization or of fusion, as the case may be, must be abstracted from (given up by) the body before the change can be effected.

1371. The following table shows the amounts of latent heat required for the fusion or vaporization for one pound of various substances, they having first been raised to the temperature at which the change takes place, and the pressure being one atmosphere, or 14.7 lb. per sq. in.

TABLE 54.

Substance.	Temperature of Fusion.	Temperature of Vaporization.	Latent Heat of Fusion. B. T. U.	Latent Heat of Vaporization. B. T. U.
Water	32°	212°	142.65	966.069
Mercury	− 37.8°	662°	5.09	157
Sulphur	228.3°	824°	13.26	
Tin	446°		25.65	
Lead	626°		9.67	
Zinc	680°	1,900°	50.63	493
Alcohol	Unknown	173°		372
Oil of Turpentine	14°	313°		124
Linseed Oil		600°		

The temperature of vaporization in the above table is the boiling point of the liquid under the ordinary atmospheric pressure of 14.7 lb. per sq. in.

The variation of the boiling point by changes in pressure differs greatly in various liquids. The temperature of fusion, or the *melting point*, is similarly affected by changes in pressure, but the amount of the variation is unimportant for all the purposes of heating and ventilation.

Example.—If 5 lb. of ice having a temperature of 10° below zero be mixed with hot water having a temperature of 200°, what weight of hot water will be required to melt the ice and bring the temperature of the mixture up to 60°?

Solution.—The temperature of the ice is 10 + 32 = 42° below the freezing point. The amount of heat required to raise its temperature to the freezing point will be 42 × .504 (specific heat) × 5 lb. = 105.84 heat units. To liquefy the ice at 32° will require 5 lb. × 142.65 (latent heat of fusion) = 713.25 heat units. Then, to change the ice into water at 32°, 105.84 + 713.25 = 819.09 heat units must be applied to it. To bring its temperature up to 60°, there must be 60 − 32 = 28° × 5 lb. = 140 heat units added, which makes the total quantity of heat required, 819.09 + 140 = 959.09 heat units.

The hot water is to be cooled from 200° down to 60°; thus, each pound will furnish $200 - 60 = 140$ heat units. By dividing the total amount required by this quantity, we find that $959.09 \div 140 = 6.85$ lb. of hot water will be required. Ans.

1372. Mixtures of Steam and Water.—Let W and t_1 represent the weight and temperature of the steam, and let w and t_2 represent the weight and temperature of the water. Let t represent the final temperature of the mixture, and L the latent heat of the steam at the given temperature. Then, the temperature of a mixture of steam and water may be found by means of the following rule:

Rule.—*When steam and water are mixed the steam condenses. To find the final temperature of the mixture, add together the latent heat and the temperature of the steam and multiply the sum by the weight of the steam. To this product add the product of the weight and temperature of the water, and divide the sum so obtained by the sum of the weights of the steam and water. The quotient will be the temperature of the mixture.*

That is,
$$t = \frac{W(L + t_1) + w\,t_2}{W + w}.$$

EXAMPLE.—If 8 lb. of steam at 212° are run into a barrel containing 300 lb. of water at 43°, what will be the final temperature?

SOLUTION.—The weight of the steam is $W = 8$ lb., the latent heat $L = 966.069$ B. T. U., the temperature t_1 is 212°. The weight of the water is $w = 300$ lb.; the temperature is 43°. Hence, according to the last rule, the final temperature t is

$$t = \frac{W(L + t_1) + w\,t_2}{W + w} = \frac{8 \times (966.069 + 212) + 300 \times 43}{8 + 300} = 72\tfrac{1}{2}^\circ. \quad \text{Ans.}$$

STEAM.

1373. Steam is *water vapor;* that is, it is *water* changed into a *gaseous state* by the application of *heat.*

The process of changing water (or other liquid) into vapor by means of heat is called **ebullition** or **boiling.**

1374. When a vessel containing water is placed in contact with a flame of fire, the air which is generally contained in the water is first driven off, and escapes from the surface without noise. The molecules of the water which are in contact with the part of the vessel nearest the fire receive heat first, and begin to move more and more rapidly until, finally, the cohesion between them is overcome, and they rise into the main body of water. At last, the whole mass of water becomes heated through, and the molecules are then able to rise through the body of the water, overcome the pressure on the surface of the water, and escape in the form of gas. Then the water is said to boil.

It is plain that if the pressure on the surface of the water is increased, it will require extra work to force the molecules to the surface against this increased pressure. That is, more heat must be expended upon the water to make it boil, and, therefore, the boiling point will be raised. We have seen that when water boils in the open air, exposed, therefore, to the atmospheric pressure of 14.7 lb. per sq. in., the boiling begins when a temperature of 212° is reached. If the pressure on the surface is increased to say 32 lb. per sq. in., the water will not boil until it reaches a temperature of 254°. On the other hand, if the pressure is lowered to 6 lb. per sq. in., the water will boil when it reaches 170°. Hence, we have the following law:

An increase of pressure on the surface of a liquid raises the temperature at which it boils; a decrease of pressure lowers the temperature at which it boils.

1375. When steam is in contact with the water from which it is generated, it is called **saturated steam.** This is the condition of steam in a boiler. According to the law just given, the temperature of saturated steam depends upon the pressure only. When the steam in a boiler shows a gauge pressure of 60 pounds, its temperature *must be* 307°. A thermometer placed in a boiler could be used to tell the pressure of the steam. It would be as accurate, though not as convenient, as the steam gauge.

Steam, if not in contact with water, may be heated like air or any other gas until its temperature is higher than the boiling point. For instance, let a quantity of water be placed in a cylinder as shown at *a*, Fig. 525. Suppose, for convenience, that the area of the cylinder is 100 sq. in.; then, the pressure of the atmosphere upon the piston is

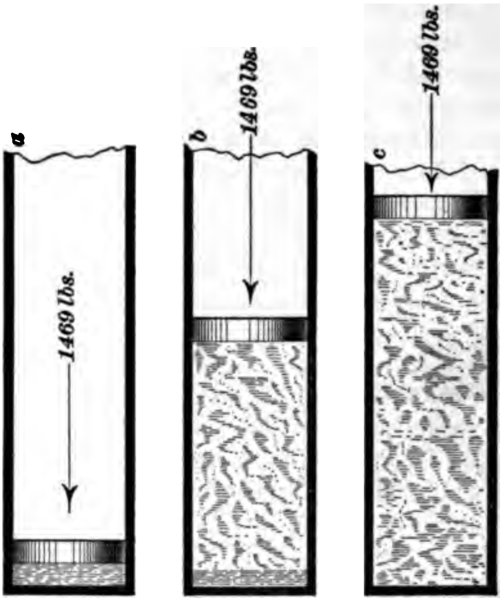

FIG. 525.

14.69 × 100 = 1,469 lb. The number 14.69 is a little more exact than 14.7.

1376. When a part of the water is changed to steam, as shown at *b*, Fig. 525, the steam is in a saturated state, and its temperature is 212°. When, however, the water is all changed to steam, as shown at *c*, any further addition of heat will raise the temperature of the steam, while the pressure, will, of course, remain at 14.69 lb. per sq. in. Steam in this condition is said to be **superheated steam.** The specific heat of superheated steam is .4805, or say .48 for ordinary purposes. Hence, .48 of one B. T. U. is required to raise the temperature of superheated steam one degree. The temperature of saturated steam can not be raised if the pressure remains constant. All the heat is expended in changing water to steam, and until all the water is vaporized the temperature remains constant.

STEAM TABLES.

1377. Whenever the pressure of saturated steam is changed, there are other properties which also change with it. These properties are the following:

1. The temperature of the steam.
2. The number of B. T. U. required to raise a pound of water from 32° (freezing) to the temperature of the steam. This is called the **heat of the liquid.**
3. The number of B. T. U. required to change a quantity of water at a given temperature into steam of the same temperature. This is called the **latent heat of vaporization,** or simply **latent heat.**
4. The number of heat units required to change a pound of water at 32° to steam of the required temperature and pressure. This is called the **total heat of vaporization,** or simply **total heat.**

It is plain that the *total heat* is the sum of the *heat of the liquid* and the *latent heat.* That is, total heat = heat of liquid + latent heat.

5. The **specific volume** of the steam at the given pressure; that is, the number of cubic feet occupied by a pound of steam of the given pressure.
6. The **density** of the steam; that is, the weight of one cubic foot of the steam at the given pressure.

1378. All of the above properties vary for different pressures. For example, when water boils under atmospheric pressure, the temperature is 212°; the heat of the liquid is 180.531 B. T. U.; the latent heat, 966.069 B. T. U.; the total heat, 1,146.6 B. T. U. A pound of steam at this pressure occupies 26.37 cu. ft., and a cubic foot of steam weighs about .037928 lb. When the pressure is 70 lb. per sq. in. above vacuum, the temperature is 302.774°; the heat of the liquid is 272.657 B. T. U.; the latent heat is 901.629

B. T. U.; the total heat, 1,174.286 B. T. U.; a pound of the steam occupies 6.076 cu. ft., and a cubic foot of the steam weighs .164584 lb.

These properties have been determined by direct experiment for all ordinary steam pressures. They are given in the table of the Properties of Saturated Steam.

1379. Explanation of the Table.—Column 1 gives the pressures from 1 to 300 pounds. These pressures are above vacuum. The steam gauges fitted on steam boilers register the pressure above the atmosphere. That is, if the steam is at atmospheric pressure, 14.7 lb. per sq. in., the gauge registers 0. Consequently, the atmospheric pressure must be added to the reading of the gauge to obtain the pressure above vacuum. In using the table, care must be taken *not* to use the gauge pressures without first adding 14.7 lb. per sq. in.

Pressures registered above vacuum are called **absolute pressures.** The pressures given in column 1 are *absolute.* Absolute pressure per sq. in. = gauge pressure per sq. in. + 14.7.

Column 2 gives the temperature of the steam when at the pressure shown in column 1.

Column 3 gives the **heat of the liquid.** It will be noticed that the values in column 3 may be obtained approximately by subtracting 32° from the temperature in column 2. If the specific heat of water were exactly 1.00 at all temperatures, it would, of course, take exactly $212 - 32 = 180$ B. T. U. to raise a pound of water from 32° to 212°. But actually, the specific heat of water is slightly greater than 1.00 when the temperature of the water is over 62°, and it, therefore, takes 180.531 B. T. U. to raise the temperature of a pound from 32° to 212°.

Column 4 gives the **latent heat of vaporization,** which is seen to decrease slightly as the pressure increases.

Column 5 gives the **total heat of vaporization.** The values in column 5 may be obtained by adding together the corresponding values in columns 3 and 4.

Column 6 gives the weight of a cubic foot of steam in pounds. As would naturally be expected, as the pressure rises, the steam becomes denser and weighs more per cubic foot.

Column 7 gives the number of cubic feet occupied by one pound of steam at the given pressure. It will be noticed that the corresponding values of columns 6 and 7 multiplied together always produce 1. That is, for 31.3 pounds gauge pressure (corresponding to 46 lb. in Col. 1) we have .11088 × 9.018 = 1.000, very nearly.

Column 8 gives the ratio of the volume of a pound of steam at the given pressure to the volume of a pound of water at 39.1°. The values in column 8 may be obtained by dividing 62.425, the weight of a cubic foot of water at 39.1°, by the numbers in column 6.

EXAMPLES ON THE USE OF THE STEAM TABLE.

EXAMPLE 1.—Calculate the heat required to change 5 pounds of water at 32° into steam at 92 pounds pressure above vacuum.

SOLUTION.—From column 5, the total heat of one pound at 92 lb. pressure is 1,180.045 B. T. U.

$$1,180.045 \times 5 = 5,900.225 \text{ B. T. U. Ans.}$$

EXAMPLE 2.—How many heat units are required to raise $8\frac{1}{2}$ pounds of water from 32° to 250°?

SOLUTION.—Looking in column 3, the heat of the liquid of one pound at 250.293° is 219.261 B. T. U. $219.261 - .293 = 218.968$ B. T. U. = heat of liquid for 250°. Then, for $8\frac{1}{2}$ pounds it is $218.968 \times 8\frac{1}{2} = 1,861.228$ B. T. U. Ans.

EXAMPLE 3.—How many foot-pounds of work will it require to change 60 pounds of boiling water at 80 lb. pressure, absolute, into steam of the same pressure?

SOLUTION.—Looking under column 4, the latent heat of vaporization is 895.108; that is, it takes 895.108 B. T. U. to change 1 pound of water at 80 lb. pressure into steam of the same pressure. Therefore, it takes $895.108 \times 60 = 53,706.48$ B. T. U. to perform the same operation upon 60 pounds of water.

$$53,706.48 \times 778 = 41,783,641.44 \text{ foot-pounds. Ans.}$$

EXAMPLE 4.—Find the volume occupied by 14 pounds of steam at 30 pounds, *gauge* pressure.

SOLUTION.—30 pounds, gauge pressure, = 30 + 14.7 = 44.7 pounds. absolute pressure. The nearest pressure in the table is 44 pounds. and the volume of a pound of steam at that pressure is 9.403 cubic feet. The volume of a pound at 46 pounds pressure is 9.018 cu. ft. 9.403 − 9.018 = .385 cu. ft., the difference in volume for a difference in pressure of 2 lb. $\frac{.385}{2} = .1925$ cu. ft., the difference in volume for a difference in pressure of 1 pound. .1925 × .7 = .135 cu. ft., the difference in volume for a difference in pressure of .7 pound. Therefore, 9.403 − .135 = 9.268 cu. ft. is the volume of one pound of steam at 44.7 pounds pressure. The .135 cu. ft. is subtracted from 9.403 cu. ft., since the volume is less for a pressure of 44.7 lb. than for 44 lb.

$$9.268 \times 14 = 129.752 \text{ cu. ft.} \quad \text{Ans.}$$

EXAMPLE 5.—Find the weight of 40 cu. ft. of steam at a temperature of 254°.

SOLUTION.—The weight of one cubic foot of steam at 254.002° is, from the table, .078839 pound. Neglecting the .002°, the weight of 40 cu. ft. is, therefore,

$$.078839 \times 40 = 3.15356 \text{ pounds.} \quad \text{Ans.}$$

EXAMPLE 6.—How many pounds of steam at 64 pounds pressure, absolute, are required to raise the temperature of 300 pounds of water from 40° to 130°, the water and steam being mixed together ?

SOLUTION.—The number of heat units required to raise one pound of water from 40° to 130° is 130 − 40 = 90 B. T. U. (Actually, a little more than 90 would be required, but the above is near enough for all practical purposes.) Then, to raise 300 pounds from 40° to 130° requires 90 × 300 = 27,000 B. T. U. This quantity of heat must necessarily come from the steam. The total heat at 64 pounds pressure, absolute, is (see steam table, column 5) 1,172.466 B. T. U. above 32°. 130° − 32° = 98°. Then, total heat above 130° is 1,172.466 − 98 = 1,074.466 B. T. U. = number of heat units given up by one pound of steam and used to heat the water.

It, will, therefore, take $\frac{27,000}{1,074.466} = 25.13$ pounds of steam to accomplish the desired result. Ans.

EXAMPLE 7.—How much heat will be given off by the condensation of 35 lb. of steam having a temperature of 206° ?

SOLUTION.—The following method of solving gives results close enough for practical purposes: The steam table shows that the latent heat of steam at 206° is about 970.4 B. T. U., and as this is the amount of heat each pound of steam gives off when it returns to water, the total amount of heat given off by the condensation of 35 lb. of steam at the above pressure will be 970.4 × 35 = 33,964 B. T. U. Ans.

NOTE.—It will be observed that the steam pressure in this example is below the atmosphere, being only 13 lb., absolute, and that there will be a vacuum in the apparatus of 14.7 — 13 = 1.7 lb.

EXAMPLE 8.—It is required to heat 200 lb. of air having a temperature of zero to 70°. How many pounds of steam having a pressure of 10 lb. per sq. in., by the gauge, will be required for the operation?

SOLUTION.—To raise the temperature of 200 lb. of air through 70° will require 200 lb. × 70° × .23751 (specific heat) = 3,325.14 heat units.

The absolute steam pressure is 10 + 14.7 = 24.7 lb.

By reference to the tables it is found that one pound of steam at 24.7 lb. pressure per square inch contains a total of about 1,187 heat units. One pound of water at 70° contains about 70 heat units. The steam, in changing to water at 70°, will give off the difference in heat, which is 1,187 — 70 = 1,117 heat units per pound of weight. By dividing the total amount of heat required by the quantity thus found, we find that 3,325.14 ÷ 1,117 = 2.9768 lb. is the weight of steam required. Ans.

FREEZING MIXTURES.

1380. If a solid is dissolved in a liquid which does not act chemically upon the solid, the temperature will fall, and will continue to fall until the solid is completely dissolved. Thus, if sugar is dissolved in water, the temperature will fall several degrees.

Again, if two solid substances which will unite and form a liquid if brought together are pulverized and mixed, both will melt and form a liquid having a temperature very much lower than that of the original materials. Thus, if salt and pounded ice or snow are mixed together, they will melt, and the brine thus formed will be extremely cold.

These results are due to the fact that a considerably greater amount of heat (the latent heat) is required to maintain a substance in the liquid condition than as a solid. The latent heat which is required for liquefaction is obtained by lowering the temperature.

GENERATION OF HEAT.

1381. Strictly speaking, there is no such thing as the actual *generation* of heat, because heat always exists in the materials, and can not either be originated or destroyed.

The so-called generation of heat depends upon the fact that many substances require much greater amounts of heat to maintain their existence separately than when two or more of them are combined.

Thus, oxygen and carbon require far more heat to maintain them as separate substances than is required to maintain them when combined into carbonic acid. When fuel is burned, the oxygen and carbon unite, and only a part of their original heat is required to maintain the resultant compound; the balance is set free and warms everything in the vicinity by radiation or conduction. In a similar manner, when oxygen and hydrogen unite and form water, an enormous amount of heat is set free.

These three substances, oxygen, carbon, and hydrogen, furnish nearly all of the heat which is available for ordinary purposes. Other combinations are known, some of which, notably oxygen and silicon, produce an extremely high temperature, but they are employed for metallurgical purposes only.

1382. All chemical or mechanical compounds either give off or absorb heat at the time the combination is effected. Thus, fresh lime and water give off considerable heat in combining; and, on the contrary, plaster of Paris and water absorb much heat in solidifying.

Other forms of energy, notably electricity and mechanical energy, can be transformed into heat; but the methods are very indirect and inefficient, and the consequent expense is so high that at this date they are impracticable for ordinary heating purposes.

MEASUREMENT OF HEAT.

1383. Instruments which serve to measure the **intensity** of heat are called **thermometers** or **pyrometers.**

1384. The *quantity* of heat which is developed by combustion of fuel, or which is taken up or given off by the gases or vapors in passing from the gaseous to the liquid condition, is measured by instruments called **calorimeters.**

THERMOMETERS.

1385. If a body is heated and brought near the hand, the sensation of warmth is felt; if heat is removed from this same body and it is again brought near the hand, the sensation of cold is felt. The heat which thus manifests itself is called **sensible heat,** because any change to a hotter or colder state is indicated at once by the sense of feeling, or by the aid of instruments called **thermometers.** The more sensible heat a body possesses, the hotter it is; the more sensible heat that is taken away from it, the colder it is.

1386. The amount of sensible heat that a body may happen to possess is indicated by the word **temperature,** and by comparison with some other body having the same amount of sensible heat. Thus, a piece of iron having exactly the same amount of sensible heat as a piece of melting ice, is said to have *the temperature of melting ice.* If a piece of lead has the same amount of sensible heat as a kettle of boiling water, it is said to have *the temperature of boiling water*, etc.

Owing to the imperfection of our senses, it is impossible to determine by their aid the temperature of different bodies with any degree of accuracy; hence, for this purpose, thermometers are used. In these instruments the effects of heat upon bodies are made use of in obtaining the temperature, the most common method being to utilize the expansive effect of heat upon liquids. Liquids are used for ordinary purposes in place of solids or gases, because in the first the expansion is too small, and in the second too great. Mercury and alcohol are the only liquids used—the former because it boils only at a very high temperature, and the latter because it does not solidify at the greatest known cold produced by ordinary means.

1387. In Fig. 526 is shown a mercurial thermometer with two sets of graduations on it. The one on the left, marked *F*, is the **Fahrenheit thermometer,** so named after its inventor, and is the one commonly used in this country and in England; the one on the right, marked *C*, is the **Centigrade thermometer,** and is used by scientists throughout the world on account of the graduations being better adapted for calculations. As will be seen, the instrument consists of a glass tube having a bulb at one end and closed at the other, so as to keep the air out. Before closing the upper end, the tube is partially filled with mercury, and the air above it is driven out by heating the mercury to near its boiling point, when the tube above the mercury will be filled with mercurial vapor. It is now sealed, and on cooling, the vapor condenses and a vacuum results. The expansion or contraction of the mercury by applying or withdrawing heat from the body with which the bulb is in contact, causes the top of the mercury column to rise or fall; and, since for equal changes of temperature the mercury rises or falls equal distances, this instrument, when properly made and graduated, indicates with great accuracy any change in temperature.

For the thermometer to be reliable the inside diameter should be the same throughout its length. In order to graduate the thermometer, it is placed in melting ice, and the point to which the mercurial column falls is marked **freezing.** It is then placed in the steam rising from water boiling in an open vessel, and the point to which the mercurial column rises is marked **boiling.**

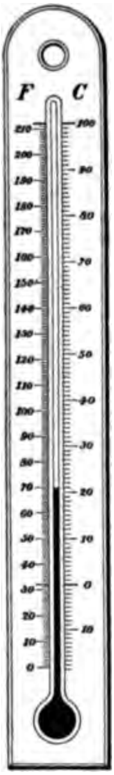

FIG. 526.

1388. There are now two fixed points: the freezing point and the boiling point. If it is desired to make a Fahrenheit thermometer, the distance between these two fixed points is divided into 180 equal parts, called degrees. The freezing point is marked 32° and the boiling point 212°; 32 parts are marked off from the freezing point downwards, and the last one is marked 0°, or zero. The graduations are carried above the boiling point and below the zero point as far as desired. This thermometer was invented in 1714, and was the first to come into general use.

In graduating a Centigrade thermometer, the freezing point is marked 0°, or zero, and the boiling point 100°; the distance between the freezing and boiling points is divided into 100 equal parts; these equal divisions are carried as far below the freezing point and above the boiling point as desired. The reason that Fahrenheit placed the zero point on his thermometer 32° below freezing was because that was the lowest temperature he could obtain, and he supposed that it was impossible to obtain a lower one. Where there is any doubt as to the thermometer used, the first letter of the name is placed after the degree of temperature. For example, 183° F. means 183° above zero on the Fahrenheit instrument. 183° C. would mean 183° above zero on the Centigrade instrument.

In Russia and a few other countries another thermometer is used, called the **Reaumur**; the freezing point is marked 0°, or zero, and the boiling point 80°, the space between these two points being divided into 80 equal parts. 183° R. would mean 183° above zero on the Reaumur thermometer.

1389. Of these three thermometers, the Centigrade is used the most; but since the Fahrenheit instrument is the one in general use in this country, all temperatures given in this Paper will be understood to be in Fahrenheit degrees, unless otherwise stated. In order to distinguish the temperatures below the zero point from those above, the sign of subtraction is placed before the figures, indicating the number of degrees below zero. Thus, – 18° C. would mean that the temperature was 18° below the zero point on the Centigrade thermometer; – 25.4° F. would mean 25.4° below zero on the Fahrenheit thermometer. The point of absolute zero, or – 460° F., is the point at which all vibratory motion of the molecule ceases. It is supposed that at this temperature, and under a heavy pressure, so as to bring the molecules close enough together, even hydrogen would be solidified. The absolute zero on the Centigrade scale is $-273\frac{1}{3}°$ C.

1390. The **absolute temperature** is the temperature measured above the point of absolute zero. (See Art. **1410.**) Hence, on the Fahrenheit scale the absolute temperature T is $460° + t°$, when $t =$ the ordinary temperature, and is above zero. If $t°$ is below zero, its value is negative and the absolute temperature T is $460° + (-t°) = 460° - t°$.

NOTE.—Hereafter, whenever temperatures are mentioned, t will denote the ordinary temperature indicated by the thermometer, and T the absolute temperature.

EXAMPLE.—What are the absolute temperatures of 212°, 32°, and −39.2°?

SOLUTION.—Since no scale is specified, the Fahrenheit is the one intended to be used.

$460° + 212° = T = 672°$. Ans.
$460° + 32° = T = 492°$. Ans.
$460° - 39.2° = T = 420.8°$. Ans.

The absolute temperature on the Centigrade scale is $T = 273\frac{1}{3}° + t°$ when $t°$ is above zero, or $T = 273\frac{1}{3}° - t°$ when $t°$ is below zero.

EXAMPLE.—What are the absolute temperatures corresponding to 100°, 4°, and −40° C., respectively?

SOLUTION.—$273\frac{1}{3}° + 100° = T = 373\frac{1}{3}°$ C.
$273\frac{1}{3}° + 4° = T = 277\frac{1}{3}°$ C.
$273\frac{1}{3}° - 40° = T = 233\frac{1}{3}°$ C.

1391. It is frequently necessary to change from one scale to the other. For example, what would 80° C. be on the Fahrenheit scale?

Since the number of degrees between the freezing point and boiling point on the Centigrade scale is 100, and on the Fahrenheit 180, it is evident that if $F =$ the number of degrees Fahrenheit, and $C =$ the number of degrees Centigrade,

$$F : C :: 180 : 100, \text{ or } F = \tfrac{180}{100}\,C = \tfrac{9}{5}\,\text{C}.$$

Also, $C = \frac{100}{180}\,F = \frac{5}{9}\,\text{F}$. Therefore,

1392. To change Centigrade temperatures into their corresponding Fahrenheit values:

Rule.—*Multiply the temperature, Centigrade, by $\frac{9}{5}$ and add 32°; the result will be the temperature Fahrenheit.*

1393. To change Fahrenheit temperatures into their corresponding Centigrade values:

Rule.—*Subtract 32° from the temperature, Fahrenheit, and multiply by $\frac{5}{9}$, and the result will be the temperature Centigrade.*

Expressing these two rules by means of formulas, let t_c = temperature Centigrade, and t_f = temperature Fahrenheit. Then,

$$t_f = \tfrac{9}{5}\, t_c + 32^\circ.$$

$$\text{and } t_c = \tfrac{5}{9}\,(t_f - 32^\circ).$$

Example.—Change (*a*) 100° C., (*b*) 4° C., and (*c*) − 40° C. into Fahrenheit temperatures.

Solution.—(*a*) $t_f = \frac{9}{5}\, t_c + 32 = \frac{9}{5} \times 100 + 32 = 212^\circ$ F. Ans.
(*b*) $t_f = \frac{9}{5} \times 4 + 32 = 39.2^\circ$ F. Ans.
(*c*) $t_f = \frac{9}{5} \times -40 + 32 = -72 + 32 = -40^\circ$ F. Ans.

Example.—Change (*a*) 60° F., (*b*) 32° F., and (*c*) − 20° F. into their corresponding Centigrade temperatures.

Solution.—(*a*) $t_c = \frac{5}{9}\,(t_f - 32) = \frac{5}{9}\,(60 - 32) = 15\frac{5}{9}^\circ$ C. Ans.
(*b*) $t_c = \frac{5}{9}\,(32 - 32) = 0^\circ$ C. Ans.
(*c*) $t_c = \frac{5}{9}\,(-20 - 32) = \frac{5}{9} \times -52 - 28\frac{8}{9}^\circ$ C. Ans.

1394. Since mercury freezes at − 37.84° F. (this corresponds to − 38.8° C.) some other means must be had to measure temperatures below this point. For this purpose alcohol is used in place of mercury. This liquid has never been frozen until very recently, and then only at an extremely low temperature obtained artificially. Since alcohol vaporizes at 173° F., the boiling point of water can not be marked on the alcohol thermometer by heating it to that point. The freezing point is determined in the same way as that of mercury. An alcohol thermometer and a mercurial thermometer are placed in a vessel containing hot water or other liquid, and the point to which the alcohol column rises is marked. Suppose that the point to which the mercury column rises is marked 132°, then the distance between the point marked and the freezing point would be divided into 132 − 32 = 100 equal parts, and each one of these parts

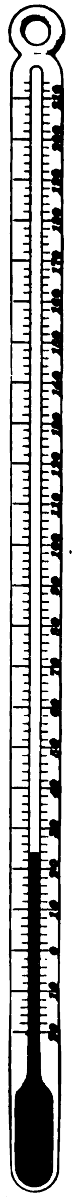

FIG. 527.

would correspond to one degree on the mercurial thermometer. These equal divisions are then carried below the zero point as far as is desired.

The kind of instrument shown in Fig. 526, having the graduations on a wooden or metal plate, is unsuitable for any purpose which requires accuracy.

The graduations should be engraved on the glass tube, as shown in Fig. 527. All thermometers which are used for testing, or for any accurate work, are made in this way.

1395. Until recently, instrument makers removed all of the air from the thermometer tubes, and left the space above the mercury a vacuum. The boiling point of the mercury was lowered thereby, and, in consequence, mercurial thermometers could not be used in temperatures much exceeding 500° F. Thermometers are now made, however, which are serviceable and accurate up to 900° F., although the ordinary boiling point of mercury is at 662°.

This result is accomplished by filling the space above the mercury with gas under heavy pressure, and thereby raising the boiling point. Great care is necessary in using these instruments at high temperatures in order to avoid breakage.

1396. Alcohol Thermometers. — For measuring low temperatures, alcohol is used in the thermometer tube instead of mercury. As before stated, mercury becomes a solid at about 38° below zero, but alcohol remains fluid at — 200°. As alcohol boils at about 173°, these instruments must not be exposed to heat exceeding 150°.

1397. Air Thermometers.—For measuring high temperatures, the **air thermometer** may be used.

The temperature to which this instrument may be subjected is limited only by the nature of the material of which the bulb is composed. The bulb may be made of iron or platinum, or of porcelain. Porcelain bulbs will serve excellently for all temperatures up to 1,200°. The construction of this instrument is shown in Fig. 528. The bulb *A* is about 1½ inches in diameter and 7 inches long. It may be applied in any position, horizontal, or vertical, or inverted. It is connected by a tube *B* (of glass or metal, as the case may require) to a glass tube *C*. A graduated tube *D* is connected by stout rubber tubing *E* to the tube *C*, as shown. The tubes are filled with mercury up to the line *a b*. When the mercury stands at exactly equal heights in both tubes (the temperature and barometric pressure of the atmosphere being at a standard degree), a permanent mark is made upon the tube *C* at the level of the mercury. When the bulb is exposed to heat, the air within it will expand and will drive the mercury downwards in the tube *C*, and upwards in *D*. The latter tube should then be raised until the mercury rises in *C* to the mark before made. The air is thus confined to a constant volume. The difference in the level of the mercury in the tubes *C* and *D* indicates the tension or expansive force of the air confined in the bulb. The volume of air being constant, its tension is strictly proportional to the temperature. The graduations upon the tube *D* may be made to indicate the temperature, or the pressure, or both.

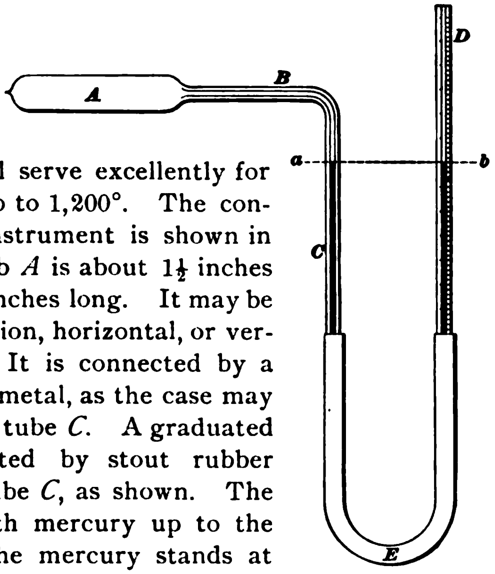

FIG. 528.

1398. There is another variety of thermometers, called **metallic thermometers,** which operate by the unequal expansion of two metals. The thermometric element is usually constructed as shown in Fig. 529. Two thin strips of metal *a* and *b*, usually brass and steel, are soldered together throughout their whole length, and are firmly fastened to a block *c*. If the temperature falls, the brass *a* contracts more than the steel *b*, and the compound bar bends to the curve *d*; if the temperature rises, the brass expands most, and compels the bar to bend in the reverse direction, as shown by the curve *e*. This thermometric element may be made of almost any shape desired, either straight or curved.

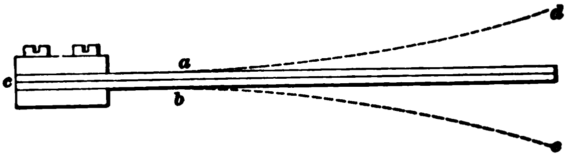

FIG. 529.

1399. Fig. 530 shows the interior mechanism of a metallic thermometer which is now in successful use. The thermometric bar *a* is fastened to a block *b*, and a light fork

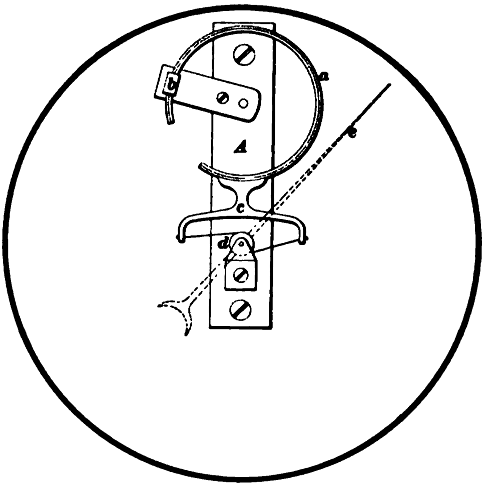

FIG. 530.

c is soldered to its free end. The ends of the fork are connected by a fine cord which wraps around, and is secured to, the small pulley *d*. The outer end of the pulley spindle is attached to a hand, or pointer, *e*, which moves over a suitable dial. When the bar *a* expands or contracts from changes in the temperature, it changes the position of the fork *c*, and the pulley *d* with the pointer *e* is rotated correspondingly.

1400. Differential Thermometers.—The instruments which have just been described are not suitable for measuring small differences of temperature. Small measurements are frequently required in making experimental investigations and for testing purposes.

1401. An instrument of great delicacy, called the **differential thermometer,** has been devised for such uses. Its construction is shown in Fig. 531. It consists mainly of two bulbs *a* and *b*, which are connected by a horizontal tube *c*. The liquid fills the tube *c*, and rises part way up each of the vertical tubes. A small bubble of air, shown near the center of *c*, divides the liquid into two equal parts, and serves as an index to show the movement of the liquid. If the two bulbs are unequally heated, the difference causes the air to expand more in one bulb than the other, and so push the liquid towards the cooler bulb. The shifting of the bubble along the scale indicates by its position the difference in the temperature of the bulbs.

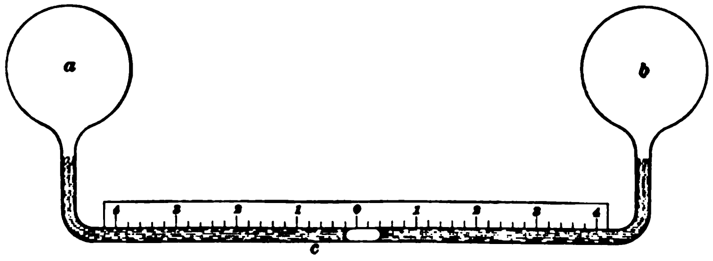

FIG. 531.

PYROMETERS.

1402. Instruments which are especially designed for measuring the temperature of ovens, chimney flues, and furnaces are called **pyrometers.** Most of them are merely varieties of metallic thermometers. The **Siemens water pyrometer,** however, depends upon the specific heat of water. It consists of a copper cup holding about 3 pints, which is thoroughly protected against loss of heat by a covering of felt, except that the top is left open. A small block of copper is carefully weighed, and then placed in the flue or furnace where the temperature is to be measured. A carefully measured amount of water is placed in the cup and its temperature noted. When the copper block has attained the heat of the furnace, etc., it is quickly removed and dropped into the cup, where it gives up its heat to the water. The rise of temperature is closely watched, and the maximum temperature is noted. The difference between the original and maximum temperatures of the water shows the amount of heat it receives from the block of copper. The mode of computing the temperature of the furnace is illustrated in the example given in Art. **1368.** For very high temperatures platinum is used instead of copper.

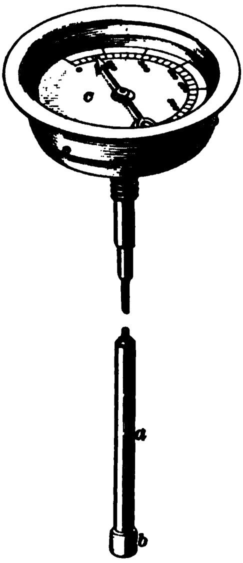

FIG. 532.

1403. A common variety of metallic pyrometer is shown in Fig. 532. The casing, or tube, *a*, is made of some metal that will endure the heat and withstand corrosion. The expanding elements are contained within the tube *a*, and consist of a tube of iron and a central rod of copper, which are united at the end near the cap *b*. The difference in the expansion of the two metals is utilized, by mechanism very similar to that in a steam gauge, to move the index hand over the graduated dial *c*.

These instruments are used by inserting the stem into the flue through which hot gases are passing, and are usually left in place for permanent use.

In using the instrument, no readings should be taken until it has had time to become thoroughly heated through. The hole through which the stem of the instrument is inserted must be guarded against the entrance of cold air or the outflow of burning gas against the dial case.

RECORDING THERMOMETERS.

1404. It is very desirable, in many instances, to have a record of the temperature which is maintained within a room by the heating apparatus, and also to know the extent of the daily fluctuations of the temperature of the atmosphere. These objects may be accomplished by means of *recording thermometers.*

1405. Maximum and Minimum Thermometers.—When it is desired to know only the highest and the lowest temperatures which occur within any certain period of time, instruments called *maximum thermometers* and *minimum thermometers* may be used.

1406. The **maximum thermometer** is a mercurial thermometer having its stem laid horizontally. The best variety is called "Negretti's," after its inventor. Its construction is shown in Fig. 533. The tube is choked close to the bulb as at *a*, so that when the mercury is driven forwards by the rise of temperature it is retained in the tube when the mercury in the bulb subsequently contracts. The mercury can be driven back by swinging the instrument, bulb downwards, at arm's length.

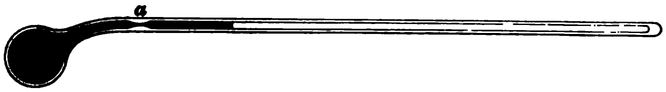

FIG. 533.

Another variety of maximum thermometer is constructed with a small piece of steel wire in the tube. This wire is pushed forwards by the mercury as it expands, and is left in place when the mercury retreats. Thus, its position indicates the greatest temperature which occurred since a previous observation. The wire is gradually affected by the mercury, however, so that the instrument becomes unreliable.

1407. The **minimum thermometer** is also constructed with a horizontal stem, as shown in Fig. 534. The liquid used is alcohol, and the minimum temperature is indicated by the position of a small float which is enclosed within the tube. When the alcohol contracts, the float will follow the retreating liquid, but when it expands, the liquid will flow past the float, thus leaving it at the point of lowest temperature. In reading the indication of the instrument, the position of the forward end of the float is noted as in *a*.

As alcohol is vaporized at moderate heat, this thermometer should not be exposed to the direct rays of a bright sun, but should be shaded. Frequently, maximum and minimum thermometers are mounted together upon a single stand, for more convenient use.

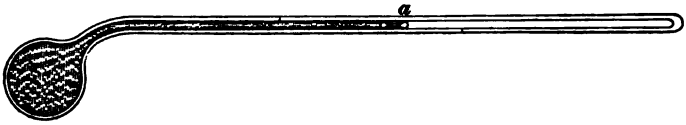

FIG. 534.

1408. Recording Thermometers.—When it is desired to have a continuous record of the changes of temperature at any certain point, the object may be attained by means of instruments called **thermographs**, or recording thermometers.

1409. The **Draper recording thermometer** is shown in Fig. 535. It records the temperature upon a paper chart, which is attached to a revolving dial *d*. As the temperature changes, the pen *a*, which is charged with ink, is moved towards or from the center of the dial by means of a metallic thermometer, which is enclosed within the case. It traces a line upon the chart as the dial turns, and the position of this line with reference to the lines which are printed on the paper, clearly indicates the temperature which existed at any time during the period included by the chart. The dial is revolved by suitable clockwork, and makes one revolution in a day or week, as desired. The paper charts are removed daily or weekly, and can be filed away for future reference.

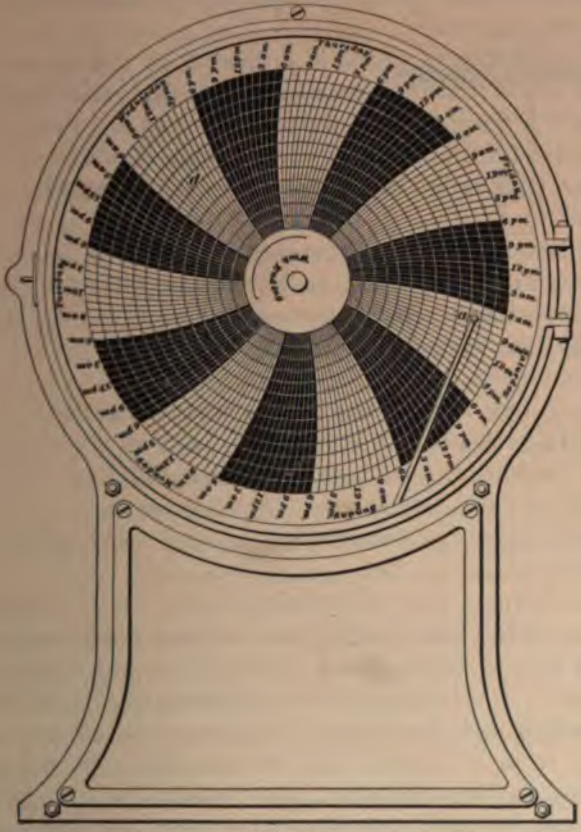

FIG. 535.

ABSOLUTE ZERO.

1410. It has been found by experiment that all perfect gases will expand $\frac{1}{460}$ of their volume when heated from zero to 1° above it. It is inferred, therefore, that the ultimate limit of contraction would be found at 460° below zero on the Fahrenheit scale, and that at this point all motion of the molecules ceases.

The temperature which is indicated by the thermometer may be converted into **absolute temperature** by adding it to 460°. Thus, a temperature of 85° by the thermometer corresponds to the absolute temperature of $85 + 460 = 545°$. On the Centigrade scale the absolute zero is 273½° below the zero point.

In this and succeeding articles, whenever it is necessary to represent temperatures by letters (as in formulas), absolute temperatures will be represented by T, T_1, T_2, etc., and ordinary temperatures by t, t_1, t_2, etc.

USE AND CARE OF THERMOMETERS.

1411. All instruments of the kind shown in Fig. 527 should be very carefully handled, because they are easily broken. Much annoyance and vexation may be avoided by always keeping the instruments in their cases when not in actual use.

Before using a mercurial thermometer, make sure that it is clean. Find out whether the thread of mercury in the tube is parted or displaced. The force which draws the mercury back into the bulb is quite weak, and if the column is parted, it can be restored to proper working order by holding it in the hand, bulb downwards, and swinging it vertically, at arm's length, a few times.

In measuring atmospheric temperature, the thermometer should be exposed to unobstructed circulation, and should be protected from the direct rays of the sun and from radiation from all warm bodies in its vicinity. It must be kept strictly dry. If there is any moisture on the bulb, it will evaporate and cause the mercury to fall to a lower point than the true temperature of the air.

1412. To ascertain the temperature of steam, water, or air, which is passing through a pipe, the pipe should be provided with **thermometer cups** which are properly adapted to the situation.

Fig. 536 shows a thermometer cup of ordinary construction. The stem *a* is made quite thin, $\frac{1}{16}$ inch or less, and the central hole should be just large enough to readily admit the bulb of the thermometer. A bore of $\frac{1}{2}$ inch is sufficient for the largest thermometer that will be required, and $\frac{3}{8}$ inch is large enough for all ordinary purposes. The cup is partly filled with mercury and the thermometer bulb is sunk into it; this mercury is a good medium for conducting heat from the cup to the thermometer bulb. The neck *b* of the cup is provided with a tapering screw thread, corresponding to a standard pipe plug, and the collar *c* is made hexagonal, to fit an ordinary wrench. The cup should be made of iron. If it is made of brass, it can not be used with mercury without damage to the brass. The depth of the cup should be sufficient in all cases to contain the entire bulb of the thermometer within that part of the stem which is actually surrounded by the hot fluid to be tested.

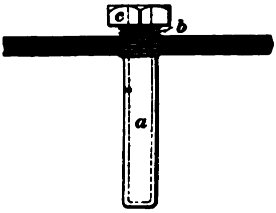

FIG. 536.

The cups should stand vertically, or as nearly so as circumstances will permit. The end of the stem should always extend at least to the center of any pipe to which it may be attached, and it may extend as much farther as desired.

1413. Thermometer cups are usually left in place as permanent fixtures. If the cups are made of brass, they should be partly filled with heavy engine oil of good quality. They should be allowed to become hot before the thermometer is inserted. The thermometer should be allowed several minutes' time in which to attain its maximum temperature before any readings are taken.

The projecting stem of the thermometer should be guarded against currents of air, hot or cold, which might influence the indications of the instrument.

In locating thermometer cups, care should be taken to

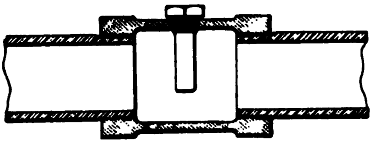

FIG. 537.

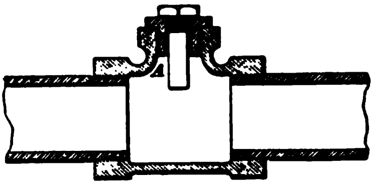

FIG. 538.

avoid all places where air might collect around the stem, and also any pockets which might be filled with partially cooled fluid. An air bubble around the stem of the cup will materially reduce the indication of the thermometer.

1414. If the cup is inserted in a T or other fitting, it should be inserted through the side, as in Fig. 537, and should not be put in as shown in Fig. 538, because of the liability of air lodging at *A*. Fig. 539 shows the proper method of inserting a cup at a vertical elbow. The stem is long enough to bring the bulb of the thermometer well below any possible collection of air at *A*. The cup is located a little forward of the center of the vertical pipe, so as to be in the middle of the current.

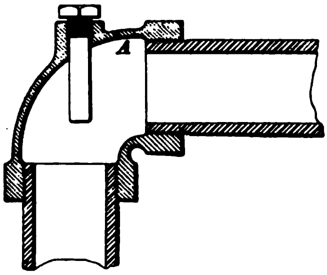

FIG. 539.

When cups can not be used, the temperature of a hot surface may be found by laying the thermometer against it, and covering the instrument with felt or other good non-conducting material. Only enough of the stem should be exposed to allow the indications to be readily observed. This method will not secure accurate results, and is not to be recommended for any purpose requiring accuracy. The thermometer will show the temperature of the pipe only, which may, or may not, agree with the temperature of the liquid within it.

CALORIMETERS.

1415. When it is desired to ascertain the *amount* of heat which any certain body will give off during combustion, or in passing from one physical condition to another, instruments called **calorimeters** are used.

These are constructed in many ways, but all of them operate by absorbing the heat which is emitted by the body under examination. The difference in the temperature of the absorbing material is measured by a thermometer. The increase in temperature, when multiplied by the weight and specific heat of the absorbing medium, shows the amount of heat given off between any two observations.

1416. For the purpose of heating and ventilation, a knowledge of the *steam calorimeter* is sufficient; therefore, all other varieties will be omitted. Two instruments are made for the measurement of the heat which is contained in steam, one called the *separating calorimeter*, for ordinary wet or dry steam, and the other called the *throttling calorimeter*, for superheated steam only.

Steam can not be superheated in the same boiler in which it is generated, nor in any apparatus in the presence of water. Superheated steam is rarely used for heating purposes; consequently, the throttling calorimeter will seldom be required. The separating calorimeter will answer all ordinary requirements, and will measure the heat contained in steam of any pressure.

1417. The construction of the **separating calorimeter** is shown in Fig. 540. The steam to be tested is passed through the pipe *a* and head *b* into the mechanical separator *c*. The steam escapes through a series of fine holes, and passes over the edge of the cup *d* into the outer space *e*. It passes out thence through the shank *f* and hose *g* to a condenser *h*, where it is condensed. The sudden change of direction of the flow of the steam in passing through the fine orifices in *c* causes the water which is suspended in the steam to be thrown down into the cup *d*. The quantity of water thus caught in the cup is shown by the gauge glass *i*.

The scale *j* is so graduated that each division indicates $\frac{1}{100}$ of a pound. The steam is thus freed from suspended water in a very perfect manner. Only pure steam passes to the condenser. The rate of the flow of steam is limited by the size of the orifice in *f*, which is usually $\frac{1}{16}$ inch. Condensation will occur, with 60 lb. of steam at the gauge, at the rate of about 1 lb. in 3 minutes. The condenser should contain 75 to 80 lb. of water. The water should be as cold as can conveniently be obtained, and should fill the condenser to or a little above the zero of the scale *v*. Each division of the scale indicates $\frac{1}{10}$ of a pound. As the steam condenses, the water level will rise, and the difference between the successive readings of the scale indicates the weight of dry steam actually condensed. Readings should be taken simultaneously upon the scales *v* and *j*, at the beginning and end of each test. The steam pressure should be accurately measured at the same time. The weight of steam actually tested is the sum of the weights of the steam condensed in *h* and the water which is caught in *d*.

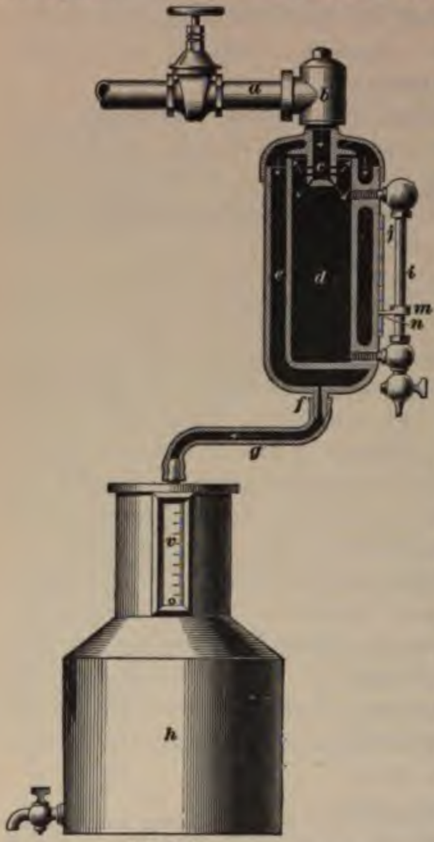

FIG. 540.

1418. To use the instrument it must be warmed up slowly, to avoid breaking the gauge glass. The full pressure of steam should then be admitted, and maintained until all tests are completed. The valve and pipe connections should be protected with good non-conducting material, but the body of the instrument and the condenser should be left uncovered.

The collecting nipple should be made of $\frac{1}{2}$-in. pipe, and should be as short as possible, so as to avoid all condensation inside it. The collecting end should be rounded on the edges, and the interior surface should be smooth. White lead or paint should not be used in making connections, because it is very liable to get into the separator and clog the fine orifices through which the steam has to pass. The nipple should be open at the end only; no perforations should be made in its sides. The end of the nipple should extend to the center of the steam pipe in all cases, as shown in Fig. 541. This will prevent any condensed water that may trickle down the sides of the pipe from entering the calorimeter with the steam. If it be attached to a steam drum, or reservoir, it should extend at least 3 in. into the interior, and the attachment should be made at the side or top, never at the bottom, of the drum.

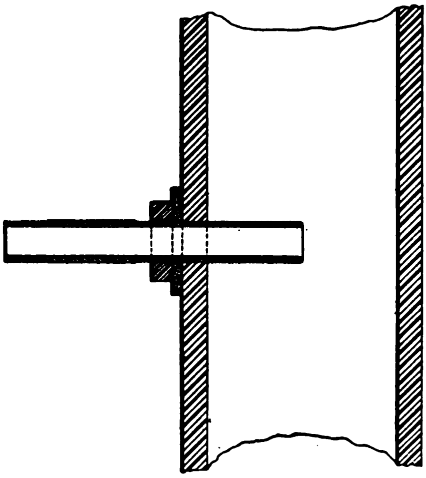

FIG. 541.

1419. Quality of Steam.—The method of computing the *quality* of the steam which is tested by the separating calorimeter is as follows:

EXAMPLE.—The increase of water in the condenser within a certain time is 2.80 lb., and the separator gains in the same time .20 lb. of water; what is the quality of the steam ?

SOLUTION.—It appears that the sample of steam which was received by the instrument was composed of 2.80 lb. of pure dry steam, mixed with .2 lb. of entrained water; therefore, the percentage of quality may be found by dividing the actual weight of pure steam by the total weight of the sample; thus,

$$\frac{2.80}{2.80 + .20} = .9333, \text{ or } 93.33 \text{ per cent.}$$

The percentage of moisture is

$$\frac{.20}{3.00} = .0667, \text{ or } 6.67 \text{ per cent.}$$

The quality of the steam is, then, 93.33 per cent. Ans.

MEASUREMENT OF THE HEAT IN FLUIDS.

1420. In order to measure the amount of heat which is contained in any certain amount of *steam*, and which will be given off by it in cooling and condensing, it is necessary that the *pressure* and *dryness* of the steam be carefully ascertained.

The steam which is used for heating purposes and for power is seldom dry, but is mixed with a greater or less percentage of water, which is suspended in the steam in the form of vapor.

The presence of water in the steam greatly impairs its value as a heating agent. Thus, 10 pounds of wet steam containing 10 per cent. of moisture consists of 9 pounds of dry steam and 1 pound of hot water. At a pressure of 26 pounds (about 11½ lb. by the gauge), we find from the table of Properties of Saturated Steam that

9 lb. of dry steam contain	10,690.2 B. T. U.
1 lb. of water contains	243.3 B. T. U.
10 lb. of wet steam contain	10,933.5 B. T. U.
10 lb. of dry steam contain	11,878.2 B. T. U.
Loss due to moisture =	944.7 B. T. U

1421. Heat Contained in Water.—The quantity of heat which will be given off by a current of *hot water*, in cooling through any certain range of temperature, may be found by measuring the velocity of the current and computing the weight of the water which passes through the pipe per minute. The weight thus found should be multiplied by the number of degrees of temperature through which the water is to be cooled. The product is the number of heat units which will be given off per minute by the current in question. Owing to the fact that the specific heat of water varies slightly at different temperatures, the result will be slightly incorrect. If great accuracy is desired, the weight of the water should be multiplied by the difference in heat units per pound, as shown in column 3 of the steam table.

1422. Heat Contained in Air.—If a current of *hot air*, of a given volume of flow per minute, is cooled down through a certain number of degrees, the quantity of heat given off in the process may be computed by the following rule:

Rule.—*Multiply together the given volume of the air, the number of degrees through which it is cooled, and the amount of heat contained in 1 cubic foot of air at the original temperature given, as shown in columns 3 and 6 of Table 55. This product should then be divided by the original temperature. The quotient will be the amount of heat given off in heat units.*

EXAMPLE.—A current of hot air having a temperature of 150° and a volume of 400 cubic feet per minute is cooled in passing through a certain room to 65°; what amount of heat is given off per minute?

SOLUTION.—From Table 55, the heat contained in 1 cu. ft. at 150° is 2.3196 B. T. U. Applying the rule just given,

$$\frac{400 \times (150 - 65) \times 2.3196}{150} = 525.78 \text{ B. T. U. Ans.}$$

1423. The weight of a cubic foot of air at any temperature and pressure may be calculated by

Rule.—*Multiply the pressure in pounds per square inch by 2.702, and divide the product by the absolute temperature.*

That is, $$W = \frac{2.702p}{T},$$

where W = weight of 1 cubic foot of air in pounds, p = pressure in pounds per square inch, and T = absolute temperature.

TABLE 58.

PROPERTIES OF AIR

at a pressure of 14.7 lb. per sq. in.

Temperature, F.	Weight per Cubic Foot, Lb.	B. T. U. Given Up by 1 Cu. Ft. of Air in Cooling to 0° from	Temperature, F.	Weight per Cubic Foot, Lb.	B. T. U. Given Up by 1 Cu. Ft. of Air in Cooling to 0° from
0	.08635	.0000	75	.07424	1.3225
2	.08597	.0408	80	.07355	1.3975
4	.08560	.0813	85	.07288	1.4713
6	.08523	.1214	90	.07222	1.5438
8	.08487	.1613	95	.07157	1.6149
10	.08451	.2007	100	.07093	1.6847
12	.08415	.2398	110	.06968	1.8205
14	.08380	.2786	120	.06848	1.9518
16	.08344	.3171	130	.06732	2.0786
18	.08309	.3552	140	.06620	2.2013
20	.08275	.3931	150	.06511	2.3196
24	.08206	.4678	160	.06406	2.4344
28	.08139	.5413	170	.06305	2.5458
32	.08073	.6136	180	.06206	2.6532
36	.08008	.6847	190	.06111	2.7577
40	.07944	.7547	200	.06018	2.8587
45	.07865	.8406	210	.05929	2.9572
50	.07788	.9249	220	.05841	3.0521
55	.07712	1.0074	230	.05756	3.1444
60	.07638	1.0885	240	.05674	3.2343
65	.07566	1.1681	250	.05594	3.3216
70	.07494	1.2459	260	.05517	3.4069

Example.—What is the weight of a cubic foot of air at a temperature of 60°, the pressure being 14.7 lb. per sq. in. ?

Solution.—Applying the rule last given,

$$W = \frac{2.702 \times 14.7}{460 + 60} = .07638 \text{ lb.},$$

the same result as given in Table 55. Ans.

Having found the weight of 1 cubic foot of the air at any given temperature, the number of B. T. U. required to heat this air to a higher temperature, or which will be given up in cooling to a lower temperature, may be found by applying rule, Art. **1365.** The weight used in applying that rule should always be the weight of a cubic foot at the *original* temperature. Thus, in the example given in Art. **1422,** the weight of 1 cubic foot at the original temperature (150°) is, from Table 55, .06511 lb. Applying rule, Art. **1365,** the heat given up by 1 cubic foot in cooling from 150° to 65° is

$$U = c\,W(t_1 - t) = .23751 \times .06511\,(150 - 65) = 1.31446 \text{ B. T. U.}$$

Hence, 400 cu. ft. will give up 1.31446 × 400 = 525.78 B. T. U., the same result as obtained above.

Example.—How much heat will be required to warm 400 cubic feet of air to a temperature of 150°, the temperature out of doors being 10° ?

Solution.—The weight of 1 cu. ft. at 10° is .08451 lb. Hence, applying rule, Art. **1365,** the number of B. T. U. required to heat 400 cu. ft. from 10° to 150° is

$$U = .23751 \times .08451\,(150 - 10) \times 400 = 1{,}124 \text{ B. T. U. Ans.}$$

VOLUME AND WEIGHT OF AIR.

1424. The volume of air and its weight per cubic foot change with the temperature. The change in volume may be computed by the following:

Rule.—*Reduce both the original and final temperatures to absolute temperatures. Multiply the original volume by the* *final absolute temperature and divide by the original absolute temperature. The quotient will be the final volume.*

Or, let V = the original volume, V_1 = final volume, T = original absolute temperature, and T_1 = final absolute temperature; then,

$$V_1 = \frac{V T_1}{T}.$$

EXAMPLE.—What will be the volume of 400 cubic feet of air having a temperature of 150°, when it is cooled to 10°?

SOLUTION.—Applying the above rule,

$$V_1 = \frac{400\,(460 + 10)}{460 + 150} = 308.19 \text{ cu. ft.} \quad \text{Ans.}$$

1425. The change in weight of a given volume of air may be computed from the following

Rule.—*Multiply the original weight by the original absolute temperature, and divide the product by the final absolute temperature. The quotient will be the final weight.*

Or, letting W = original weight and W_1 = final weight,

$$W_1 = \frac{W T}{T_1}.$$

EXAMPLE.—A chimney of 1 square foot area and 120 feet high is filled with hot air at a temperature of 450°; the temperature of the atmosphere is 60°; what is the difference in the weight of the air before and after it is heated?

SOLUTION.—The volume of the air is 120 cubic feet. The original weight is (see Table 55) $120 \times .07638 = 9.1656$ lb., and the absolute temperature is $60 + 460 = 520°$. Then, applying the last rule,

$$\frac{9.1656 \times 520}{460 + 450} = 5.2375 \text{ lb.}$$

The change in weight $= 9.1656 - 5.2375 = 3.9281$ lb. Ans.

CIRCULATION.

1426. The *diffusion* of heat in fluids is accomplished by conduction. In liquids and gases the process is aided by the motion of the particles of the substance among themselves, as explained in Arts. **1353** to **1355**.

The tendency of convection currents is to merge into streams or currents of considerable magnitude. The movement of these large principal currents is called **circulation.** The *rapidity of circulation* will depend upon the following considerations:

1. Upon the amount of heat received per minute on a given area of surface.

2. The extent of the heating surface in proportion to the volume of the fluid.

3. The place of application of the heat, whether it is at the top, side, or bottom of the mass.

4. The conductivity of the fluid.

5. The viscosity of the fluid.

FORCE OF CIRCULATION.

1427. The circulation of those fluids which are commonly used for heating purposes, that is, air, steam, and hot water, is directly due to the difference of temperature in the various parts of the enclosure or apparatus. But the force which compels the flow of the fluid from one part of the apparatus to another is much less with air or hot water than with steam.

In the case of hot air, the impelling force which is available for moving it forwards is the difference between its total weight and the weight of an equal volume of cold air at the temperature of the surrounding atmosphere.

The difference in the elastic force or pressure of the hot air and that of the atmosphere into which it escapes is small, and it helps to promote the circulation only in a small degree.

In the case of hot water the sole impelling force is that of gravity, being the difference in weight of the water in the descending parts of the apparatus, and that of an equal volume of water at the average temperature of the ascending column.

In the use of steam, however, the difference in the *elastic force* of the fluid, in the supply and return pipes, near the generator, amounts to several pounds per square inch. The *density* (weight of a cubic foot) of the steam also varies with the temperature, and the movement of the steam is assisted by gravity, in a similar manner to that of air and hot water. But the impelling force due to gravity is very small in comparison to that due to the difference in elastic force at the extremities of the system. The steam will move towards the point of lowest pressure with a force which is equal to the difference in pressure.

1428. The force which is available for moving the water in a hot-water system may be computed by the following method: The height of the descending column should be measured from the actual top of the column (which is the point at which the water begins to flow downwards) to the point where the return pipe enters the boiler. The average temperatures of the ascending and descending columns should then be carefully measured. The difference in weight of columns of water 1 inch square and 1 foot high, at the actual average temperatures thus found, may be learned by referring to column 4 of Table 51. As this column gives the weight of the water per cubic foot, however, it is necessary to divide by 144 in order to obtain the weight or pressure per square inch for each foot in height. This difference in weight between the ascending and descending columns of water, when multiplied by the height of the columns in feet, equals the total pressure per square inch, which acts as a motive force to drive the water forwards.

EXAMPLE.—What is the total motive force in a hot-water heating apparatus, when the average temperature throughout the ascending column is 230°, and in the descending column 180°, the operative height of the descending column of water being 70 ft.?

SOLUTION.—Table 51 shows that water at 180° exerts a pressure of $\frac{60.548}{144} = .4205$ lb. per sq. in. at the base of the column for each foot of height; and that water at 230° has a corresponding pressure of $\frac{59.360}{144} = .4122$ lb. per sq. in. The force available for moving the

water will then be the difference in pressure multiplied by the height of the column, which is .4205 − .4122 = .0083 lb., and .0083 × 70 = .5810 lb. per sq. in. at the base of the column. Ans.

1429. In estimating the operative height of the column, one must not include any part of the system which is located above the level of the point at which the water begins to flow downwards. The elevation of the level of the water in the expansion tank above that point does not increase the motive force of the system in any degree. It serves only to increase the static pressure equally throughout the whole system. An increase of static pressure simply raises the boiling point of the contained water, and thus admits of a higher temperature being given to the water in circulation.

CHIMNEYS AND FLUES.

1430. If a compact mass of hot air should be set free in a cold atmosphere which completely surrounds it, the hot air would instantly begin to rise. While ascending, it would lose heat by convection to the surrounding air; and these convection currents would operate to quickly disintegrate and disperse the mass among the cooler air which surrounded it.

If the original mass could have been protected by a non-conducting jacket which was open at the top, the loss of heat from its sides and the dispersion of its substance by convection currents would have been greatly retarded. The ascending movement would, therefore, have continued through a much greater distance.

A chimney operates in a similar manner to protect the column of hot air which moves within it from loss of heat, and from disintegration and dispersion into the surrounding atmosphere.

1431. It is commonly said that chimneys have a **suction,** and that they **draw** air into them. These statements are erroneous. Air, and all other fluids, move only when the pressure which impels them is greater than the pressure which opposes their movement. Hence, they are always *pushed*, and are never pulled or drawn.

In order to clearly understand the reason why hot air moves up a chimney, or flows from a flue into a room, it is necessary to examine carefully into the condition of affairs throughout the entire extent of the chimney, or flue.

For illustration, suppose that the chimney shown in section in Fig. 542 is 120 feet high, that the temperature of the hot air in the chimney is about 450°, the atmosphere being at 60°, and that the flue is closed at the top. Now, the column of air inside the chimney weighs less per cubic foot than the air outside, because it is greatly expanded by the heat. From Table 55, the weight of 1 cu. ft. of air at 60° is .07638 lb.; hence, by rule, Art. **1425,** the weight at 450° is $\frac{(460 + 60) \times .07638}{460 + 450} = .04365$. The difference $= .07638 - .04365 = .03273$ lb. The actual difference in weight of two columns, one of external and the other of internal air, each 1 foot square and 120 feet high, will be $.03273 \times 120 = 3.93$ lb. Consequently, the weight of the internal air can not balance that of the external air; therefore, it will be driven upwards against the cover at the top with a force amounting to 3.93 lb. per sq. ft., or about .027 lb. per sq. in. There will then be a higher pressure at the top of the chimney than at the base. The pressure at the bottom will be equal to that of the external atmosphere, or about 14.7 lb. per sq. in., and it will increase gradually upwards, until at the top it will be $14.7 + .027 = 14.727$ lb. per inch.

The condition of the air in the interior of the chimney is now precisely similar to that in an ordinary hot-air flue when all the registers are closed. The pressure of the hot air exceeds that of the atmosphere at each register, in proportion to its elevation above the radiator or other heating apparatus. When a register is opened, the hot air flows into the room, because its pressure exceeds the pressure of the air in the room. Now, if the top of the chimney be opened to the atmosphere, the whole column of hot air in its interior will be driven rapidly upwards.

But as soon as the current begins to flow, the internal pressure falls, and when the current attains its full speed the internal pressure at the top will fall to about that of the atmosphere.

The weight of the column of hot air, however, remains the same (the temperature being maintained constant); consequently, the difference in pressure at the top and bottom will be the same as before, that is, .027 lb. per sq. in. The pressure of the hot air at the bottom of the chimney will, therefore, be about .027 lb. below that of the external atmosphere.

Now, if a water gauge, Fig. 545, is connected to the interior space at the bottom of the chimney, it will show that the exterior atmospheric pressure exceeds the interior pressure by .027 lb., which will be indicated by a difference in height of the water columns of $.027 \div .03617 = .746$ inch.

The excess of the atmospheric pressure above the interior pressure at the base of the chimney is called the **draft,** and is usually measured in *inches of water*, as explained in Art. **1442.**

1432. The tendency of all fluids is to flow towards an area of low pressure. The surrounding atmosphere can not flow down the chimney, because the internal pressure of the hot air at the top equals or exceeds the atmospheric pressure, but it can and does flow in through the grate and combustion chamber into the area of low pressure within.

The velocity of the entering air will increase until the resistance which it encounters in passing through the burning fuel, added to that due to the friction of the flues, exactly equals the draft pressure.

As soon as the air reaches the fire it is greatly expanded by the heat, usually to two or three times its former volume. As the heat is given off to the boilers, etc., and to the walls of the furnace and flues, the volume gradually diminishes until it is discharged from the top of the chimney.

1433. The theoretical velocity of the current in the chimney is equal to that acquired by a weight in falling through a distance equal to the difference between the height of a column of air at atmospheric temperature, having the same height as the chimney, and the height of the same column when expanded by the heat to the actual temperature of the gases in the chimney.

The height of the column will increase directly with the increase of absolute temperature. The velocity acquired by a falling body is in all cases very nearly 8.02 times the square root of the distance fallen through.

To find the theoretical *velocity*, in feet per second, of the gases in a chimney, or ventilating flue, proceed by the following

Rule.—*Multiply the height of the chimney in feet by the difference in temperature of the gases and of the atmosphere in degrees, and divide by the absolute temperature of the atmosphere. Extract the square root of the quotient, and multiply it by 8.02. The result will be the theoretical velocity sought.*

Or, let t = temperature of the atmosphere, t_1 = temperature of chimney gases, T = absolute temperature of atmosphere, H = height of chimney in feet, and v = velocity in feet per second. Then,

$$v = 8.02\sqrt{\frac{H(t_1 - t)}{T}}.$$

Example.—What is the theoretical velocity of the current in a chimney 120 ft. high, the temperature of the gases being 450° and that of the atmosphere 60°?

Solution.—Applying the last rule,

$$v = 8.02\sqrt{\frac{120(450 - 60)}{460 + 60}} = 76.08 \text{ ft. per sec. Ans.}$$

Example.—What will be the theoretical velocity of warm air having an average temperature of 90° in a flue 25 ft. high, the atmospheric temperature being 60°?

Solution.—Applying the same rule as in preceding example,

$$v = 8.02\sqrt{\frac{25(90 - 60)}{460 + 60}} = 9.63 \text{ ft. per sec. Ans.}$$

1434. The theoretical velocities thus computed can not be attained in practice, because of the friction and other resistances offered by the flues. The allowance which must be made for friction, etc., varies from 20 to 50 per cent. The hot air in chimneys which are attached to boilers and furnaces is mixed with a large percentage of carbon dioxide, or carbonic acid, which is much heavier than air. The weight of the hot air is thereby increased, the draft pressure is diminished, and the velocity of flow is correspondingly reduced.

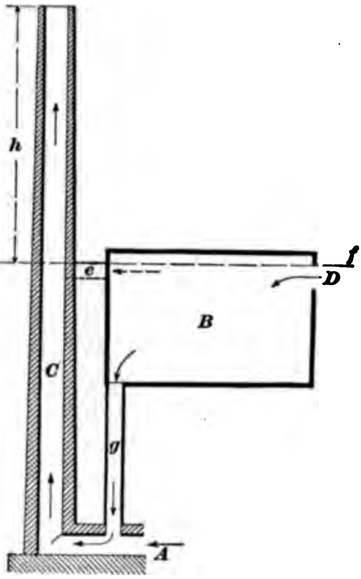

FIG. 542.

The actual, or operative, height of a chimney should be measured from the top of the stack to the *inlet* of the air, where it *enters* the furnace, or heating chamber. Only the actual difference in elevation should be considered; the horizontal distances that may be involved must be disregarded. Thus, in Fig. 542, the operative height of the chimney, when the hot air enters at *A*, is the total height of the stack *C*; but when it enters at the level of the line *f f*, the operative height is only that part which is above the line, as indicated by the distance *h*. The chimney will act as a siphon, and will draw the warm air downwards out of the room *B* through the flue *g*, provided that the opening at *A* is closed and the fresh air is taken in at *D*. The operative height of the chimney will then be equal to the distance *h*, and the draft will be about the same as though the connection to the chimney were made as shown by the dotted lines at *e*. In practice, the draft will be better when the connection is made at *e* than when the current passes down the flue *g*, because the hot air will lose some of its heat in making the longer circuit, and there will also be more friction.

Chimneys and flues which are cold, or have never had a fire connected to them, will usually exhibit a considerable draft. This is due to the fact that the earth constantly warms the air near its surface. Ordinarily, the air thus warmed rises only a short distance before it is cooled and dispersed by convection in the atmosphere, but that which passes up the chimney is protected from convection, and is maintained in an unbroken stream to the top of the stack.

The heat of the earth causes the lower rooms of a house to be warmer than the upper ones. Thus, almost any flue will show a positive current through it, because the temperature is higher at the bottom than at the top.

MEASUREMENT OF AIR.

1435. The *velocity* of air may be measured by instruments of various kinds. The velocity of a large body or current of air may be measured by means of the *anemometer*, which is shown in Fig. 543.

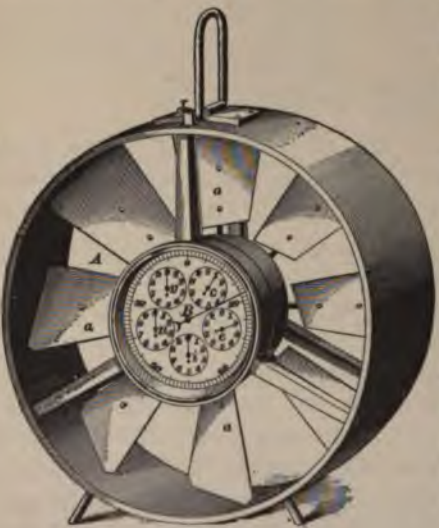

FIG. 543.

To estimate an air current correctly, it is necessary that we should know two things: First, the velocity of the current, and, second, the area of the transverse section of the covered passage through which the air flows. Knowing these, we can, by multiplying them together, find the quantity, i. e., the volume of the air flowing through the tube in a given time. The velocity of the air is always taken in linear feet per minute, and the area of the cross-section in square feet. Using these units of measure, the product gives the quantity of air passing through the tube, or flue, in cubic feet per minute. For example, let the velocity be 600 feet per minute and the area of the cross-section 1.5 square feet; then, the quantity of air entering and leaving the flue every minute will be $600 \times 1.5 = 900$ cubic feet.

1436. In order to measure the velocity, two instruments are required, a watch or other time-piece, and a wind gauge, called an **anemometer.** The anemometer, however, only measures the distance in feet moved through by the current, without any regard to the time; in other words, the index pointers on the dial indicate only the number of revolutions the wind wheel makes while the current passes through the anemometer. The anemometer, then, does not measure the *rate* of motion.

1437. The anemometer shown in Fig. 543 consists of a wind wheel A and a registering device B. The wind wheel is composed of a light spider having eight arms, to which are fastened very light blades, or vanes, a. The arms of the spider are so twisted that the blades, or vanes, make an angle of 45 degrees with the plane of the wheel, so that when the anemometer is placed in the path of an air current, the wind wheel is caused to revolve.

1438. The motion of the wind wheel is communicated by its arbor to the registering device B. This device consists of a train of gears in the reducing order of units, hundreds, thousands, etc., by means of which we take off the reading in thousands, hundreds, units, etc. The arbor of the wind wheel and also that of each gear of the train carry on their ends index pointers which show on separate dials units, hundreds, thousands, etc., as illustrated in the figure. Suppose that each index pointer is at the *0* mark of its dial. When the wind wheel has made 100 revolutions, the large pointer in the center of the dial has made one revolution, or it has moved from *0* to *0* on the large dial. Therefore, each space of the dial represents one revolution of the wind wheel. While the large pointer moved from *0* to *0*, or while the wind wheel made 100 revolutions, the pointer on the *c* dial moved from *0* to *1*, as shown. If the wind wheel makes another 100 revolutions, this pointer will move another space, or from *1* to *2*. It will move one of these spaces for each 100 revolutions of the wind wheel. Therefore, the pointer of this dial indicates hundreds of feet, and the large dial anything less than a hundred feet. If, now, the wind wheel should make a sufficient number of revolutions to cause the pointer of the dial *c* to make one complete revolution, or to cause it to move from *0* to *0*, the pointer of the dial *e* would move from *0* to *1*; therefore, the pointer of this dial indicates thousands of feet. That this is true will be clear from the following: In order to move the pointer on the dial *c* one division, the wind wheel had to make 100 revolutions, and since the pointer of the dial *c* had to move ten divisions to make one revolution, the wind wheel must make $10 \times 100 = 1{,}000$ revolutions.

In the same manner, it may be calculated and shown that the pointers of the dials *i*, *n*, and *v* indicate ten thousands, hundred thousands, and millions of feet, respectively.

All anemometers are so constructed that when the air which passes through the wind wheel moves one foot horizontally, the wind wheel will make one revolution; therefore, if the large pointer were at *0* of the large dial, and the instrument were placed in a current of air for one minute, and after removing it the pointer was at the *76* point of the dial, then the velocity of the current would be 76 feet per minute. Suppose all the pointers to be at their *0* marks, and the instrument placed in a current for one minute. If, on looking at the pointers, it is found that the pointer of the dial *e* is at *2*, that of the dial *c* at *1*, and that of the large dial at *18*, as shown in the figure, what is the velocity of the current?

Since the *e* dial records thousands of feet, we write down

2,000; since the *c* dial records hundreds of feet, we write down 100, and since the large dial records 18 feet, we write down 18. Therefore, the sum of these, or 2,118 feet, is the velocity of this current per minute.

1439. To be able to take accurate readings, anemometers are always supplied with an attachment for disconnecting the registering device while the wind wheel is in motion without stopping it. Such an attachment is shown at *r*, Fig. 543. By moving *r* to the right, the registering device is in gear and the pointers will move when the wind wheel revolves; and when *r* is moved to the left, the wind wheel may revolve, but the pointers will remain stationary.

We can obtain the best idea of the mode of action of this instrument by an example. Let us suppose we are going to take a reading. The first thing to do is to read the instrument and note the number, since it is impossible to have the instrument at zero on all the dials at all times. Suppose that the instrument is standing at *15,472*, and after it has been held 3 minutes in the current, the reading is 17,740.

Now, the last reading must be greater than that at which the instrument stood before we put it in the current by the amount $17,740 - 15,472 = 2,268$. In other words, the wind wheel made 2,268 revolutions in 3 minutes, and, therefore, in 1 minute it made $\frac{2,268}{3} = 756$ revolutions. The velocity of the air current is, then, 756 feet per minute.

Further, notice that 17,740 will be the first reading the next time the instrument is used.

When the anemometer is first held in a current, it loses from 30 to 50 revolutions before the inertia due to the moving parts is overcome. The result is that to all readings a certain constant must be added. The constant is supplied by the maker of the instrument. If 30 were the constant for the case mentioned above, the correct reading would have been $\frac{2,268 + 30}{3} = 766$ revolutions per minute $= 766$ feet per minute.

1440. The velocity of air under pressure in pipes may be measured by means of **Pitot's tube,** which is shown in Fig. 544. It consists of two tubes, *a* and *b*, which are inserted in a suitable plug *c*. The lower end of *a* is square, but that of *b* is curved to face the current, as shown. The upper ends of the tubes are connected to a water gauge *d*. Very small velocities may be measured by using, instead of the ordinary gauge as shown, the differential air gauge shown in Fig. 546.

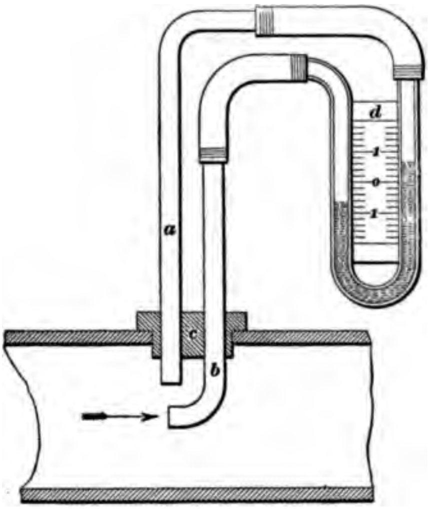

FIG. 544.

The pressure which affects the gauge is due to the momentum of the air which strikes the open end of the tube *b*. The velocity which corresponds to any particular indication of the attached water gauge may be found by means of the tables which are furnished by the instrument maker.

1441. It is difficult to measure accurately the *volume* of air which flows through an ordinary floor or wall register. The current from a floor register is usually much slower near the edges of the grating than in the middle. A fair result may be arrived at by moving the anemometer slowly back and forth over the face of the register at a distance of about three inches from it, and prolonging the test to two or three minutes. Thus, a fair average of the velocity may be obtained.

The area of the current thus measured is practically equal to that of the space within the border, or frame, of the register, the grating, or grills, being ignored.

Greater accuracy may be obtained by constructing a short box or tube over the register, and thus preventing the current from dispersing or scattering. Care should be taken that the tube does not obstruct or reduce the flow of air. The anemometer should be moved over the whole area of the current, being held close to the end of the tube. The volume of air which passes out of a room through a foul-air register may be measured with the assistance of a tube in a similar manner.

In measuring and computing the volume of air, the temperature at the time of measurement must always be taken into account. For convenience in comparing one measurement with another, the volumes should all be reduced to corresponding volumes at zero, which may easily be done by rule, Art. **1424.** In measuring the volume of air which passes through any certain pipe, care should be taken that the measurements of velocity, area of the flue, and the temperature of the air be all made at the same place.

1442. The *pressure* of air, as commonly used in heating and ventilation, is very small, and it may be measured by means of the **water gauge.** This is constructed in many forms, the simplest of which is shown in Fig. 545. It consists of a glass tube with two arms, *a* and *b*, partly filled with water. The upper end of the tube *a* is open to the atmosphere, and the end of the tube *b* is inserted in a cork *c*. When the pressure in *a* exceeds the pressure in *b*, the water will sink in *a* and rise in *b*, as shown, and *vice versa.* The difference of the level of the water in the tubes, measured in inches, indicates the difference in pressure, in *inches of water.*

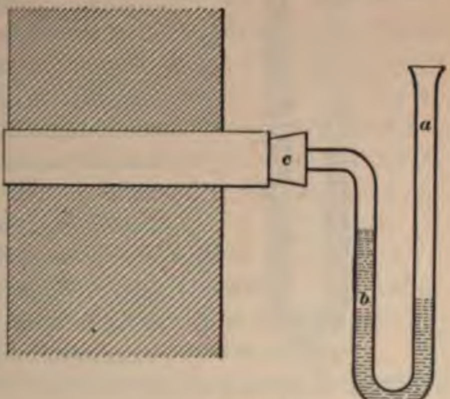

FIG. 545.

To measure the draft pressure in a chimney or flue, a connection should be made to the interior by means of a piece of ¾-in. iron pipe, which should be cemented air-tight in a hole through the brickwork. The water gauge may then be inserted in the cork *c*, and the cork pressed firmly into the end of the iron pipe, as shown, taking care that the gauge arms stand vertically. The difference in level can then be measured by means of a common rule held behind the tubes.

The water gauge is not sufficiently sensitive or delicate for the accurate measurement of very light pressures, and special modifications are made for that purpose, as shown in Figs. 546 and 547.

1443. The **differential air gauge** is shown in Fig. 546. The tubes *a* and *b* are connected to large bulbs, or chambers, *c* and *d*. The bulbs of the instrument are filled with two liquids which have a small difference in weight. Under equal pressures the lighter liquid in *c* will stand at a slightly higher level than that in *d*. When pressure is applied to *d*, for example, the dense liquid will rise in *a* until the difference in weight of the two columns, measured from the surface of the liquids in the bulbs, balances the extra pressure. The sensitiveness of the instrument will depend upon the smallness of the difference in the weight of the liquids employed. If pressure is applied to *c*, the movement of the column will be downwards, and if the oil or other light liquid should be driven past the bend at the bottom of the tubes, it will rise through the denser liquid in the tube *b*, and will impair the working of the instrument.

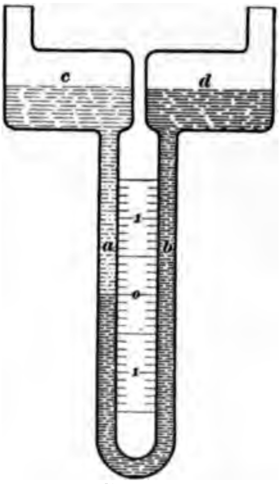

FIG. 546.

When this instrument is used as a draft gauge, the connection to the chimney is made through the bulb *c*.

1444. The **differential draft gauge** (Hoadley's) is shown in Fig. 547. Its main features are two equal chambers *a* and *b*, which are connected by means of tubes *c* and *d*, and cocks *e* and *h*. The instrument is connected to the chimney by means of the rubber tube *j* and an iron pipe similar to that shown in Fig. 545. The three-way cock *f* serves to open or close communication from the chamber *a* to the chimney, and also to admit or shut out the atmosphere through the nozzle *i*. The atmosphere may be admitted to the tube *b* through the pet-cock *g*.

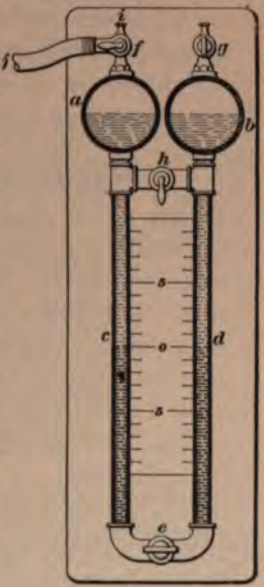

FIG 547.

The lower parts of the tubes are filled with a mixture of water and alcohol up to the zero of the scale. The upper part of the instrument is then filled with a liquid which is lighter than water, usually olive oil. Care is taken to have the surfaces of the oil in the chambers *a* and *b* at exactly the same level, and to have the water stand at equal heights in the tubes *c* and *d*. To use the instrument, the cock *h* is closed, *g* and *e* are opened, and *f* is opened to the chimney through the tube *j*. The water rises in *c*; *e* is then closed, and *f* is closed to the chimney and opened to the atmosphere.

The surface of the oil then stands higher in *a* than in *b*. By opening *h*, the oil flows from one chamber to the other, and again comes to a level in both; *h* is then closed, *e* is opened, and connection is again made to the chimney. The water then rises higher in *c*. This operation is repeated until the water refuses to rise any higher in the tube *c*, and there is no difference of level in the contents of the chambers *a* and *b*. The difference in the height of the water columns is then read from the scale.

The excess of pressure in the chamber *b* over that in *a* is then equal to the *difference* in weight of the columns of the water and oil, having a height equal to the reading taken from the scale.

It will be seen that, by using two liquids which have but a small difference in specific gravity, the instrument may be made to measure exceedingly light pressures.

FRICTION IN PIPES AND FLUES.

1445. The resistance which is encountered by air and other fluids in moving through pipes, flues, and conduits is usually spoken of as *friction*, although the term, as thus used, is not strictly accurate.

The resistance arises from several causes:

1. *Skin friction*, which is the actual friction of the fluid against the surfaces over which it passes.
2. The abrupt changes of direction of the current at elbows and tees.
3. The movement of one part of the current upon another, in passing around curves.
4. The abrupt changes in velocity, which occur at pockets and enlargements.
5. The formation of whirls, or eddies.
6. The interference of currents.

1446. Skin Friction.—The resistance due to skin friction varies: 1. Directly as the length of the pipe or flue. 2. Inversely as the diameter or (if square) the length of a side. 3. Directly as the square of the velocity. Hence, other things being equal, the pipe should be as short as possible; its diameter should be as large as possible, and the quantity passing through it in a given time should be as small as circumstances will permit. The last consideration is the most important of all, since if the quantity passing through a given pipe is doubled, the velocity is also doubled, and the resistance is increased 2^2 or 4 times.

The condition of the pipe itself, whether smooth or rough, also affects the force required to overcome the friction, a smooth pipe offering less resistance than a rough one

Hence, metal pipes are to be preferred, in this respect, to brick conduits. A polished pipe offers less resistance than a smooth one not polished. A pipe or flue having its inside covered with soot offers much greater resistance than a similar pipe that is clean.

1447. Resistance from Changes of Direction.—When a current of air encounters an obstacle, as in Fig. 548, the particles composing the current are compelled to deflect from their normal direction and move sideways sufficiently to pass by the obstruction. When a moving body is thus deflected from its course, it loses some of its kinetic energy. The energy thus lost will be expended upon the dead air at *a*, and will compress it.

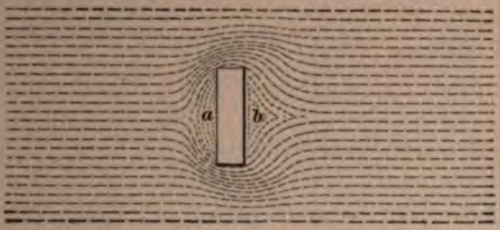

FIG. 548.

The particles of air which have passed the edges of the obstruction tend to continue their forward motion in a straight line. If they actually did so, there would be a vacuum at *b*, but the pressure existing in the outer parts of the current compels them to flow together again behind the obstruction. Thus, *a* is an area of high pressure, and *b* is an area of low pressure. The power which is expended in maintaining these two areas is taken from the current, and the motive force of the current is thereby reduced to that extent.

When a current is compelled to change its direction abruptly, the kinetic energy of the particles tends to move them as shown in Fig. 549. An area of high pressure will be formed at *a*, and another of correspondingly low pressure at *b*. The effective area of the pipe or conduit will be reduced at *c*, and the velocity of the fluid will be greater at that point than at *c* and *d*. Thus, the force which is spent in maintaining the abnormal pressures at *a* and *b*, and in imparting the increase of velocity at *c*, is all wasted.

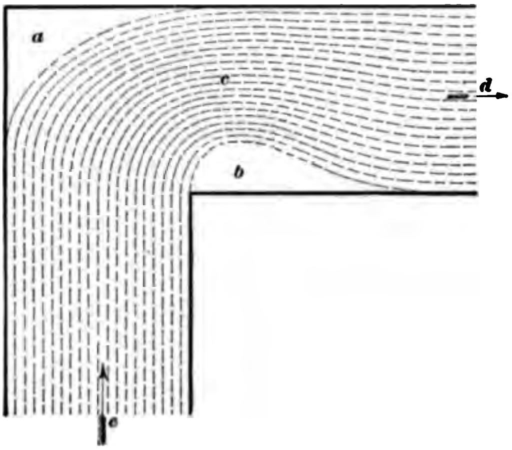

FIG. 549.

1448. Effects Produced by Curves.—If the turn is less abrupt, as in Fig. 550, the waste of energy is considerably reduced. The tendency to form high and low-pressure areas, as in Fig. 549, is nearly destroyed. But the particles of the fluid are still compelled to slide over each other. Thus, the particles at *A* and *B* will reach the points *a* and *b*, respectively, at the same time, if they travel equal distances in equal times. The power

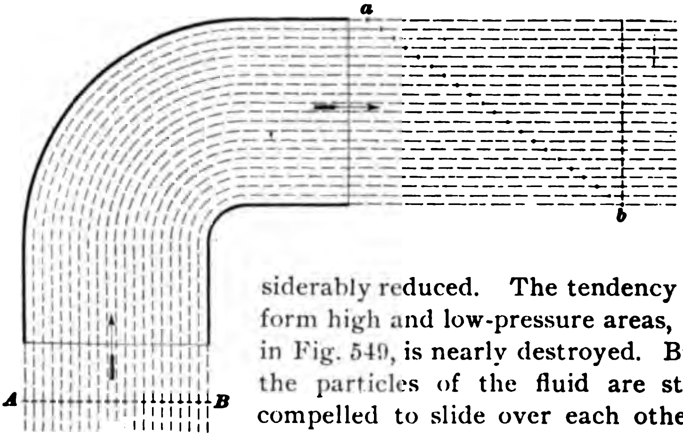

FIG. 550.

which is expended in sliding the particles of fluid upon each other is wasted.

This loss can not be avoided, whether the turn is made sharply, as in Fig. 549, with a small radius, as in Fig. 550, or with a large radius, as in Fig. 551. But the *time* which is afforded for making the change of direction (the velocity being the same in each case) is much greater in Fig. 551 than in either of the others. The force which is required to deflect a moving body from its normal path is inversely proportional to the square of the time in which the change of direction is made. Hence, if the change of direction is made in 2 seconds in Fig. 550, and in 4 seconds in Fig. 551, then $4^2 \div 2^2 = 4$ times as much force will be required when turning the curve of shorter radius.

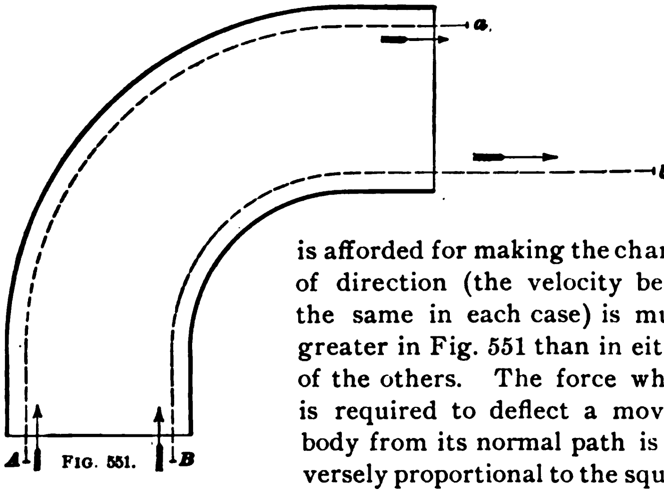

FIG. 551.

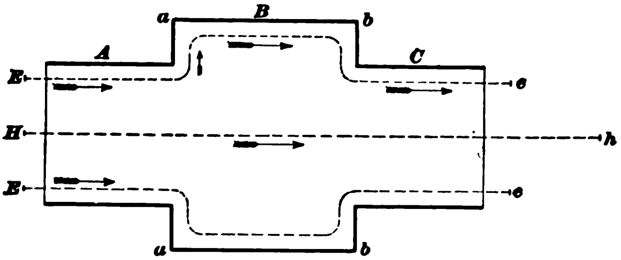

FIG. 552.

1449. Pockets and Enlargements.—The effects of **pockets** or **enlargements** in a pipe are shown in Fig. 552.

The particles *E*, which are near the surface, are compelled to change their direction twice while passing the enlargement. They flow outwards into the corners *a*, and inwards out of the corners *b*; while the particles in the center, as at *H*, pass through without interruption. Hence, the outer particles are retarded, and the central particles *H* are compelled to slide forwards upon them.

When the fluid particles pass out of the part *A* into the enlargement *B*, they are obliged to fill a space of larger diameter. To do this, their velocity must be checked; and when they enter the part *C*, their velocity must be restored and made equal to that in part *A*. To thus alternately check and accelerate the velocity requires the expenditure of energy; the energy thus spent is wasted.

1450. Whirls.—The effect of a *dead end* in a pipe or conduit is shown at *D* in Fig. 553. The particles entering at *A* travel round the dotted line *E D* to *a*, and thus move

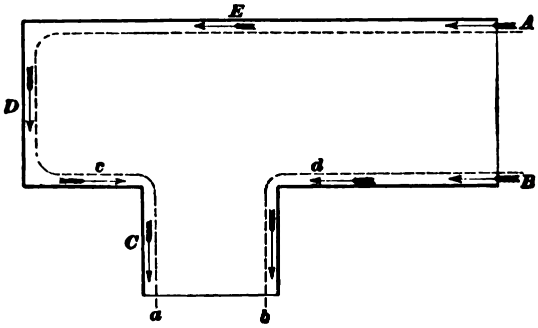

FIG. 553.

through a much longer distance than the particles which enter at *B* and travel round to *b*. At the points *c* and *d*, the currents oppose each other and thus waste energy. The dead end of the pipe will be filled with an eddying, whirling mass of fluid. The energy which is spent in maintaining these eddies is wasted.

1451. Interference of Currents.—The effect of **opposing currents** is shown in Fig. 554. This illustrates the formation of what is called the **contracted vein.** The branch *A* is attached at right angles to a tank or reservoir *B*. It will be seen that the particles which move on the lines *1* and *7* would collide if their motion were continued,

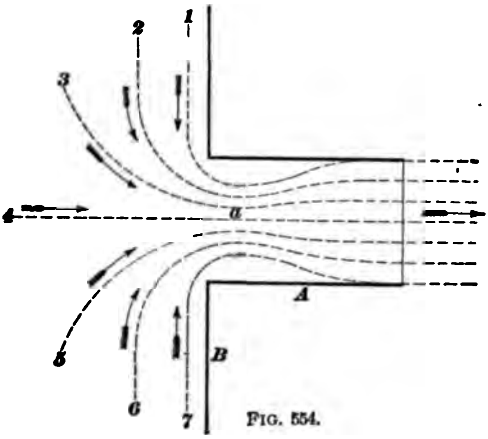

FIG. 554.

and would destroy each other's motion. Their energy is spent, however, in deflecting the other parts of the current somewhat out of their course. The effect of the opposition of the various currents is to reduce the diameter of the stream at *a* to less than the diameter of the branch *A*. Consequently, the amount of fluid which will be delivered through the branch will be less than it should be. The trouble may be remedied by providing the branch with a mouthpiece which is curved so as to properly guide the parts of the current, as shown in Fig. 555. The branch will then discharge to its full capacity.

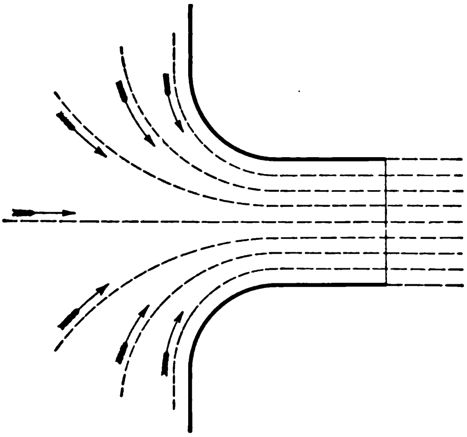

FIG. 555.

CONDUITS AND BENDS.

1452. Currents of fluid should always be guided in such a manner that they do not interfere or oppose each other's motion. The resistance offered by opposing currents in the common **T** connection, as shown at *A* in Fig. 556, is so great that the use of such a connection should never be permitted.

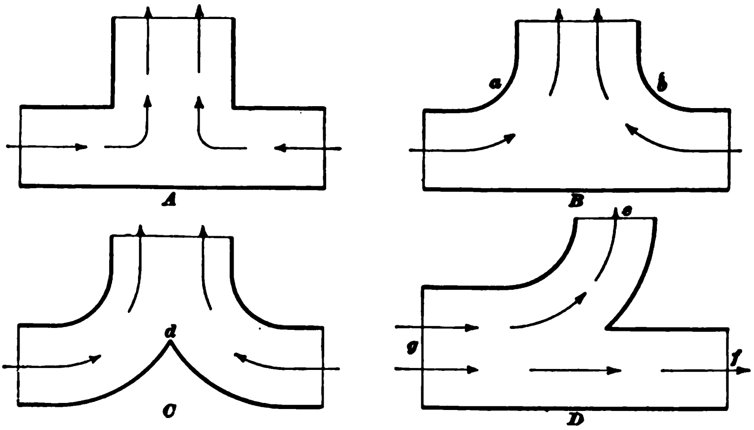

Fig. 556.

By making the corners *a* and *b* round, as shown at *B*, the evil is lessened, but only to a small degree.

The effect of the opposing currents may be reduced to a minimum by interposing between them a dividing ridge or partition *d*, as seen in the **twin elbow** *C*. If the current moves in the opposite direction to that shown by the arrows, the form *C* will still be preferable to *B* or *A*.

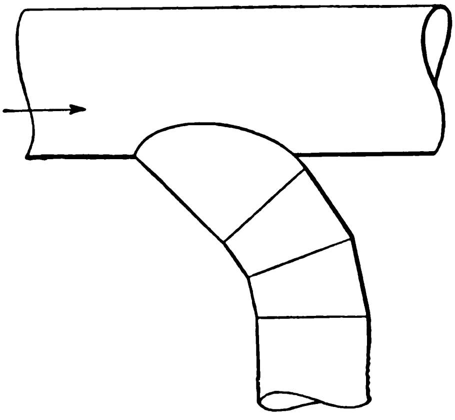

Fig. 557.

When the flow in one of the branches *f* is to continue in the same direction as in the main *g*, the other branch should be curved, as shown at *e*, in the branch *D*.

When a branch is to be taken from a main, as in Fig. 557, it should be attached at the smallest practicable angle. If the situation will not permit the form shown, and the branch must be joined at a right angle, then the connection should be made with a *gusset*, as at *a* in Fig. 558.

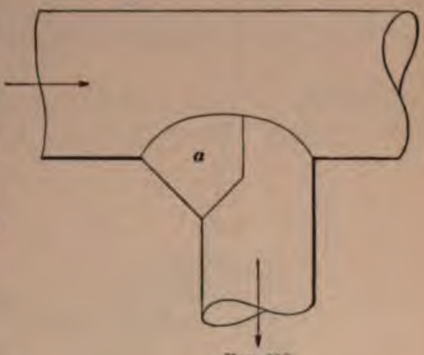

FIG. 558.

1453. The connection of the flat wall pipe *A C* to the round pipe *B*, shown in Fig. 559, is a faulty one. The change of direction which the current of air is required to make is very abrupt; the dead end *C* will also operate to retard the current by forming an eddy at that point. The proper arrangement is shown in Fig. 560 or Fig. 561, in both of which the round pipe *D* is connected to the flat pipe by means of the tapering piece *C*. The latter form is generally preferable, because less height is required in which to make the turn.

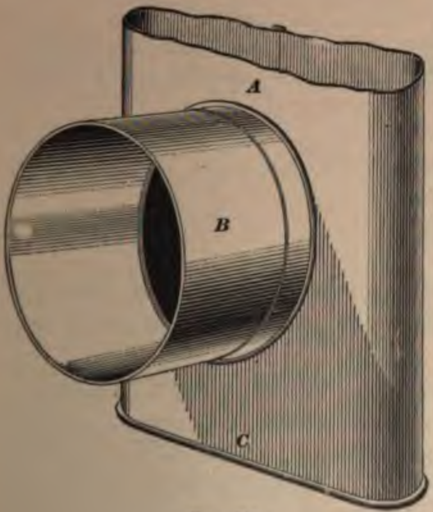

FIG. 559.

SPLITTING AIR CURRENTS.

1454. Fig. 562 shows the proper manner of dividing a main current into three branches so as to supply independent air flues. If the partitions *A* and *B* were absent, the greater part of the current would continue its motion until it was

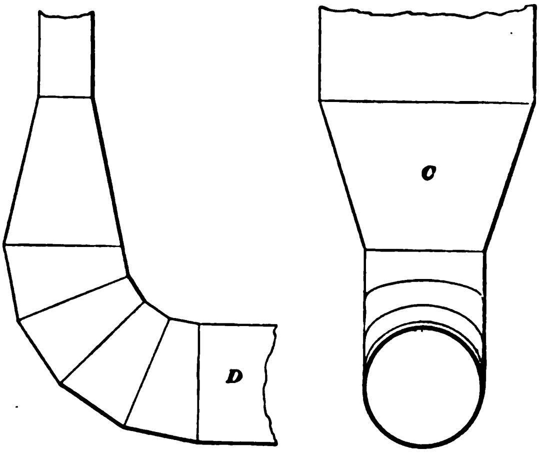

Fig. 560.

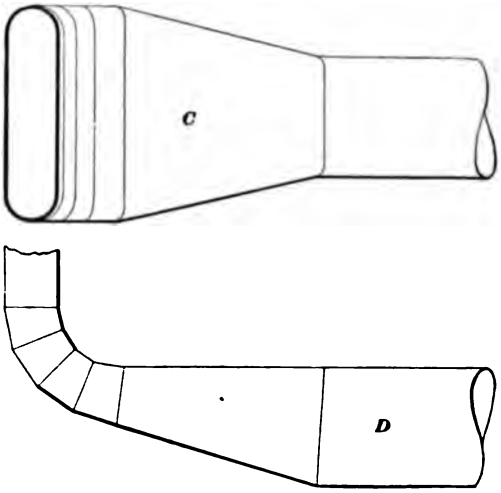

Fig. 561.

deflected by the side *C*. In that case, the flue *D* would receive a larger proportion of the current than either of the others, and the supply to the flue *F* would be quite insufficient.

The shoulders *a*, *a* against which the air impinges ought to be beveled off, instead of being left square, as in the figure.

A proper supply of air to each flue may be ensured by adjusting the partitions *A* and *B* in such a manner that they will intercept the desired proportions of the main current *before* any change is made in its direction.

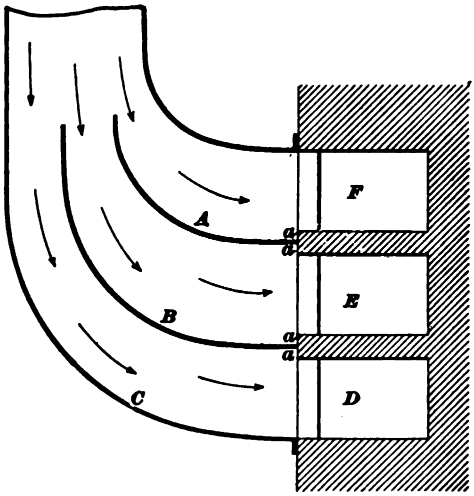

FIG. 562.

1455. Fig. 563 illustrates the proper method of splitting up a main air current into several smaller ones, and of subdividing these so as to supply a large number of vertical ducts. It shows a centrifugal fan *a* set in a fan room which is formed by air-tight partitions *p*, *p*. The fan wheel is driven by a belt from the engine *b*.

The air supply to the fan is taken in through the windows, as shown.

The fan forces the air into the main duct *c* where it becomes split into three currents c_1, *d*, and d_1. The current *d* supplies two vertical flues *e* and *f*; d_1 supplies *g* and *h*. The current c_1 is then split into two unequal currents, d_3

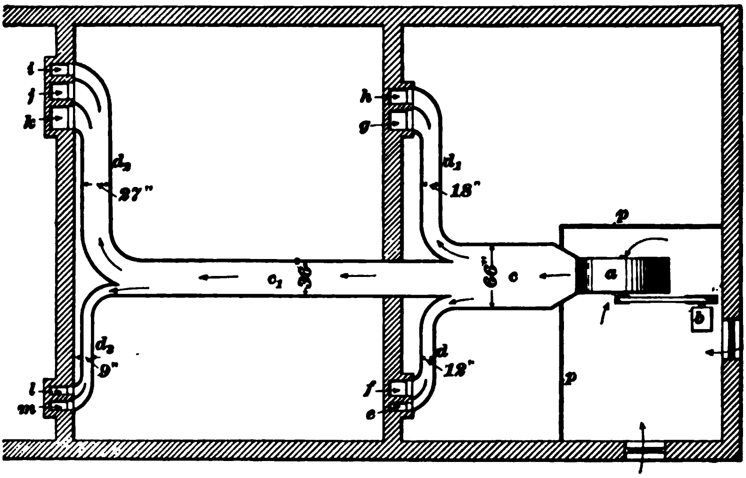

FIG. 503.

which supplies *l* and *m*, and d_2, which supplies *i j k*. The method of proportioning the various branches so as to supply all the ducts with air at a uniform pressure, or otherwise, as desired, will be fully explained later on.

SHAPE OF AIR PIPES.

1456. The shape which should be given to an air pipe or conduit depends upon several considerations.

To transmit a *given volume* of air, the circular form has the following advantages:

It requires less material to construct it.

It offers less resistance from skin friction.

It requires but little bracing to maintain it in proper shape.

To carry the *greatest volume* in the least space, the square form should be used.

For example, if a pipe is required to have an area of 254 square inches, it will be found that the desired area will be afforded by a round pipe 18 inches in diameter, or a square pipe 16 × 16 inches. The circumference of the round pipe will be 56½ inches, while that of the square pipe will be 64 inches. But the square pipe may be run through a space which is 2 inches less each way than that required for the round pipe of *equal capacity.*

WIND.

1457. Wind is a large atmospheric current which is moving towards an area of low pressure. In ordinary winds of moderate velocity, the movement is equally from all points of the compass towards the locality in which the pressure is below normal. Thus, the wind may be blowing from the east at a certain station, while at another station it will be blowing just as steadily from the west.

The area of low pressure does not usually remain stationary; it is apt to shift from one locality to another. In the winter season, this shifting movement is usually slow, from twenty to fifty miles per day, but in summer the movement is frequently much more rapid.

The area of low pressure is really the center of a storm, which may vary in force from a gentle breeze to a heavy gale. As this center passes by any certain station, the direction of the wind at that station will change, because the movement of the air will always be towards the storm center. Thus, the wind may blow from the east in the morning, and from the opposite quarter in the afternoon of the same day.

The cause of storms has been the subject of much speculation, and no definite conclusion has yet been agreed upon by scientists.

1458. The mechanical effects of the wind which are of interest in the heating and ventilation of buildings are:

First. The increase of the atmospheric pressure upon the windward side of buildings, and the corresponding decrease upon the opposite side.

Second. The increase of the draft of chimneys and flues.

Third. The reversal of currents, called **blow-downs.**

Fourth. The formation of eddies and whirls, which deposit dust and snow in undesirable places.

Fifth. The increase of evaporation and the consequent drying and cooling effects.

1459. When the wind blows against a building, the pressure of the air upon the windward side will be greater than upon the leeward side, as explained elsewhere. The air which is within the building will tend to flow out through every crevice and flue into the area of low pressure which exists upon the leeward side of the building. If, at the same time, there is no leakage of air into the building from the windward side, the atmospheric pressure within the building will fall slightly. But if there are any openings or crevices on the windward side, the air will flow from the area of high pressure (i. e., on the outside) to the inside of the building, where the pressure is at or below the normal.

If the leeward side of the building is tight, and the wind can leak through the windward side only, then the pressure within the interior of the building will be slightly increased. This extra pressure will ooze out through every crevice upon the leeward, or neutral, side of the building. It will escape through the ventilating flues also. Thus, a considerable amount of air will pass through the building notwithstanding the tightness of the leeward side.

If, on the contrary, the windward side is tight and the leeward side is leaky, only a small leakage will occur, and that will be from the interior towards the leeward side.

Thus, the amount of air which will be driven through a building by the wind (leaving out of consideration the effects upon chimneys, etc.), will depend mainly upon the tightness of the *windward* side, and not upon the condition of the leeward side.

WIND PRESSURE.

1460. The pressure of the wind upon flat surfaces at right angles to the current, at velocities ranging from 2 to 100 miles per hour, is shown in the following table:

TABLE 56.

Velocity.		Pressure per Square Foot, Pounds.	Character of Wind.
Miles per Hour.	Feet per Minute.		
2	176	.030	Perceptible breeze.
3	264	.055	Perceptible breeze.
4	352	.085	Perceptible breeze.
5	440	.133	Perceptible breeze.
7	616	.245	Perceptible breeze.
10	880	.523	Gentle breeze.
15	1,320	1.150	Light wind.
20	1,760	2.000	Light wind.
25	2,200	3.160	Strong wind.
30	2,640	4.500	Strong wind.
35	3,080	6.100	High wind.
40	3,520	7.500	High wind.
45	3,960	10.125	Gale.
50	4,400	12.500	Gale.
60	5,280	18.000	Strong gale.
70	6,160	24.500	Violent gale.
80	7,040	30.200	Violent gale.
90	7,920	41.000	Hurricane.
100	8,800	50.000	Tornado.

The pressure which is exerted by the wind per square foot of obstructed area is greatly modified by the shape of the surface.

Thus, the pressure upon the sphere, or a hemisphere with convex side towards the wind, is about one-half of that upon a flat surface of equal diameter.

EFFECTS OF WIND UPON CHIMNEYS.

1461. When the wind blows horizontally, as in Fig. 564, the air which is compressed at *A* flows up over the edge of the chimney and follows the path of the arrows *a* and *b*. This current deflects the wind somewhat, as shown by the arrows *c* and *d*, and lifts it above the leeward edge of the chimney. An opportunity is thus given for the chimney gases (which are shown by feathered arrows) to pass over the edge of the chimney into the area of low pressure at *B*. As the velocity of the wind increases, the pressure at *B* becomes less, and the chimney draft is augmented correspondingly.

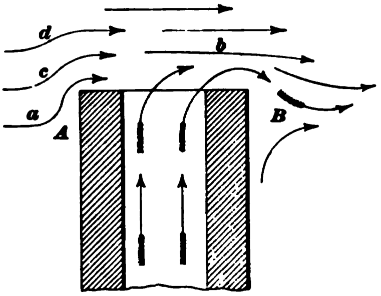

FIG. 564.

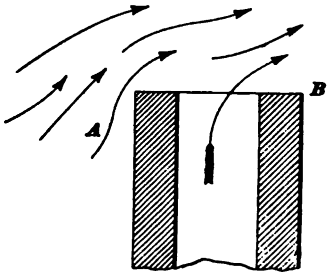

FIG. 565.

If the wind blows upwards, as in Fig. 565, the area of low pressure is formed close to the top of the chimney, as at *B*, and the escape of the chimney gases is greatly facilitated.

But if the wind blows downwards, as in Fig. 566, the escape of the chimney gases is cut off, and unless there is sufficient pressure behind them to deflect or lift the wind at the mouth of the chimney, a *back draft*, or *blow-down*, will be produced. All that part of the wind which is included between the dotted lines *a* and *b* tends to blow downwards in the chimney, but its pressure is reduced as soon as it enters the chimney, because it is then compelled to fill a larger area. Thus, the downward pressure which the wind will exert in the chimney may be found by multiplying the wind pressure by the perpendicular distance between *a* and *b*, and dividing that product by the width *c d* of the chimney. If this quotient exceeds the upward pressure of the hot gases, then a blow-down will occur.

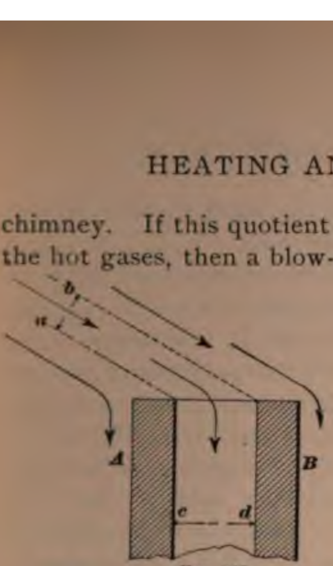

FIG. 566.

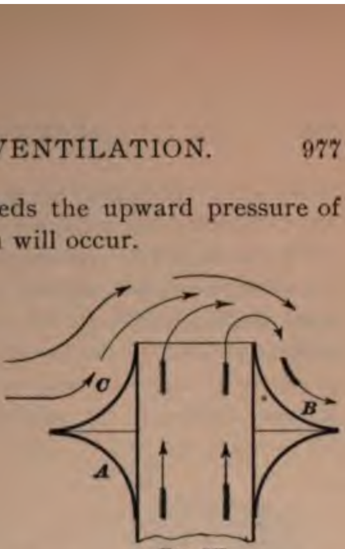

FIG. 567.

1462. The beneficial effect of ordinary horizontal winds upon the draft of a chimney may be increased by means of the circular **deflector** *C*, shown in Fig. 567. That part of the wind which is intercepted by the curved surface of *C* is deflected strongly upwards and operates to lift the main current of wind well above the top of the chimney. Thus, the chimney gases are given a good opportunity to escape over the leeward edge, as indicated by the arrows.

The influence of the wind upon a chimney is greatly affected by the location of the chimney relatively to the roofs of surrounding buildings.

1463. Fig. 568 illustrates the action of the wind upon an ordinary inclined roof. The draft of the chimney *A* will

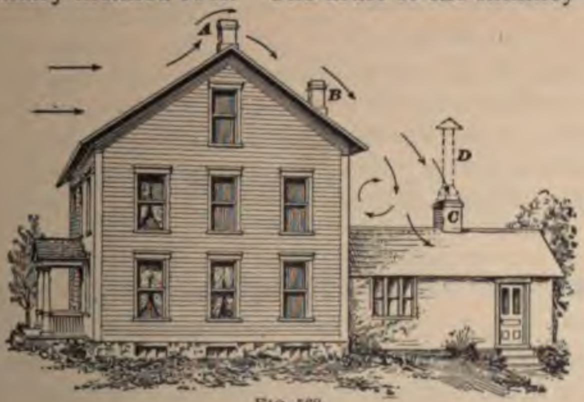

FIG. 568.

be aided by the upward slant of the wind currents, which are caused by the inclination of the roof.

The draft of the chimney *B* will be opposed and spoiled by the downward inclination of the wind currents. As the wind passes off the roof to the rear of the house, it will whirl downwards on to the lower roof, as shown. These downward currents will interfere seriously with the draft of the chimney *C*, and will in many cases drive the smoke down the chimney and out into the interior of the house.

This trouble may be remedied by extending the chimney by means of a pipe and cowl *D*. The outlet for the smoke is thus carried above the region of downward currents.

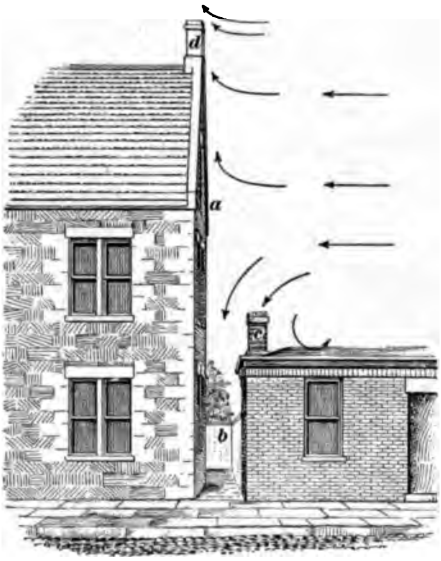

Fig. 569.

1464. Fig. 569 shows the behavior of the wind when it encounters a large vertical surface, such as the end of a building. The greater part of the current which is intercepted by the wall *a* is deflected upwards, and the draft of the chimney *d* will be considerably increased. A part of the wind will be deflected downwards into the alley-way *b*, and will cause strong horizontal currents lengthways of the passage. It will also blow downwards into the chimney *c*.

COWLS.

1465. The term **cowl** is applied in a general way to all apparatus or fixtures which are placed over the top of chimneys or ventilating flues, etc., to aid the draft. They serve to protect the ascending current of hot gases within the flue from the influence of contrary wind currents, which might oppose or even overbalance and reverse this current. They also serve to facilitate the escape of the warm gases into the area of lower pressure, which always exists upon the leeward side of the chimney or ventilating shaft while the wind is blowing. During calm weather, the cowl always obstructs the draft somewhat.

The plain cowl *E*, which is shown in Fig. 570, protects the flue from all possible blow-downs. The direction of the wind currents is indicated by the plain arrows, the course of the chimney gases being indicated by feathered arrows. The cone serves as a barrier between the top of the rising column of gases and the current of wind that may be blowing crossways or downward, preventing any considerable interference between them. The ascending column of gas is not compelled to lift or deflect the currents of wind, as it must do when the chimney is uncovered. The diameter of the cone should be from 2 to 2½ times that of the pipe to which it is attached, and the distance from the edge of the pipe to the under surface of the cone should not exceed one-half the diameter of the pipe. The plain cowl may be improved by adding to it a deflecting collar, as shown at *C* in Fig. 571.

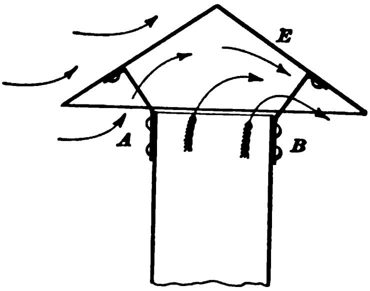

FIG. 570.

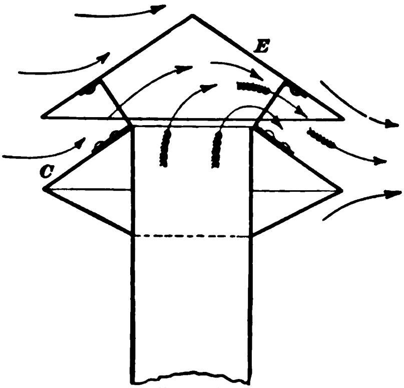

FIG. 571.

1466. The maximum efficiency of the cowl may be attained by combining with it several secondary cones, as shown at *F* and *G* in Fig. 572. This construction is quite bulky, and it offers considerable resistance to the wind; consequently, the area of low pressure upon the leeward side *B* is quite large, and the pressure is correspondingly low. The passage of the gases out of the chimney into the partial vacuum thus formed is very easy and direct.

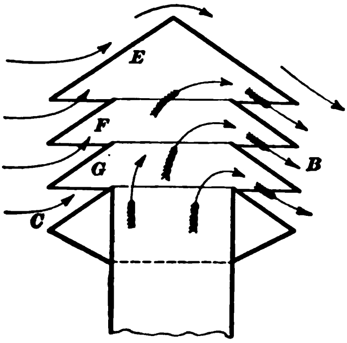

FIG. 572.

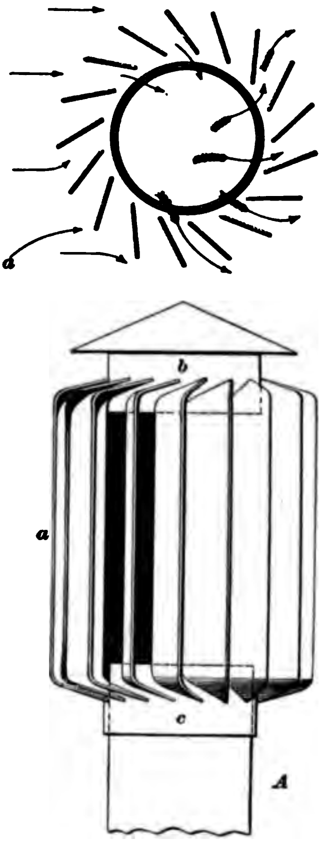

FIG. 574.

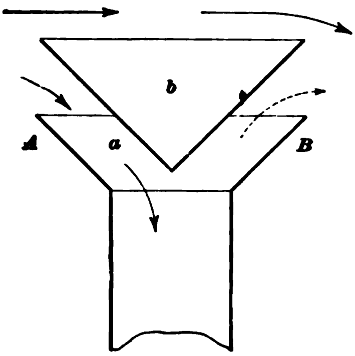

FIG. 573.

1467. The wind may be utilized to drive a current of air downwards in a pipe, such as an inlet or supply pipe. Fig. 573 shows an arrangement for this purpose. The pipe is provided with a funnel *a*, and a cone *b*, having its apex downwards. A part of the wind which strikes the cone will be deflected downwards into the pipe, as shown by the arrows. But there will be an area of low pressure at B, and a part of the contents of the pipe will escape into it and so out of the pipe, as shown by the dotted arrow; consequently, some of the air will be lost. This device is called an **induction,** or **blowing, cowl.**

1468. The cowl shown in Fig. 574 is composed of a series of vanes *a*, which are set at an angle to the radius of the circle, as shown in the cross-section. They are attached to two collars, *b* and *c*, and the openings between their inner edges afford an exit for the chimney gases. The plain arrows show the course of the wind currents, and the feathered arrows show how the chimney gases escape into the area of low pressure.

The wind currents are deflected advantageously upon one side only, but the escaping gases are protected from interference to a considerable extent.

Sometimes this apparatus is mounted upon a pivot, or a central spindle, and is allowed to rotate; but it is doubtful if any advantage is gained thereby.

1469. **Automatic cowls** are commonly made as shown in Fig. 575. An elbow *a*, having a funnel mouth *b*, is mounted so as to turn freely upon a central spindle *c*, as shown. The vane *v* catches the wind, and operates to keep the funnel always turned away from the wind. This device for aiding the draft of chimneys is very effective, but it is difficult to maintain in good working order. The pivot corrodes so rapidly that the elbow is apt to stick fast and fail to operate.

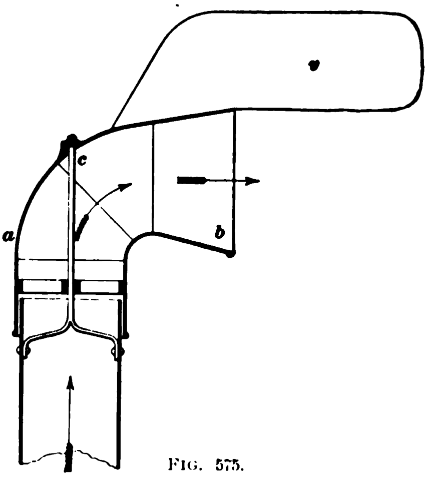

Fig. 575.

This apparatus may be used to produce a downward current, for ventilating purposes, by changing the vane *v* so that it will hold the funnel towards the wind instead of away from it.

1470. The cowl shown in Fig. 576 is provided with a blowing cone *a*, which causes the cowl to operate as an ejector. The wind caught by the cone gathers into a small current of high velocity, and as this current emerges into the mouth of the elbow or tube *b* it communicates its velocity to the gases at the top of the chimney, forcing them ahead with it, and creating a partial vacuum around the cone. The gases from below then rush upwards with an augmented velocity, owing to the increased difference of pressure. This apparatus is called an **automatic eduction cowl.**

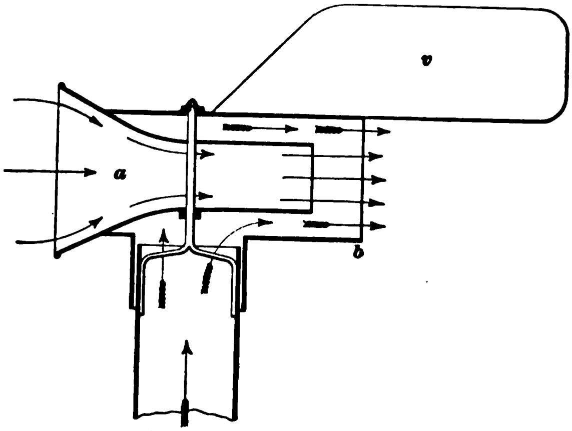

FIG. 576.

AIR AND GASES.

1471. The physical properties of gases are quite different from those of liquids. If two or more gases are confined in the same enclosure or chamber, each gas will expand throughout the entire space, precisely as though no other gas were present.

The pressure, or tension, of each gas will depend upon the proportion between its weight and the volume of the space within the chamber. The pressure shown by a gauge attached to the chamber will be the total of the pressures of the several gases confined therein.

Each gas will diffuse equally throughout the whole space; therefore, a mixture of gases will not separate into strata or layers by standing quietly for a long time, unless the gases are more than saturated. Stratification will begin when complete saturation is obtained.

Some of the heavy gases diffuse slowly, and if the opportunity for diffusion is restricted, the body of gas may remain in the bottom of the enclosure for a long time. Thus, carbonic acid gas may lie in the bottom of a covered pit or in a deep well, because the facilities for diffusion are too small to disperse it faster than it is generated.

If two compound gases, having a considerable difference in their capacity for heat, are mixed and maintained under pressure, they will exhibit a strong tendency to separate in cooling. Thus, air and ordinary steam, when contained in pipes, will separate when the steam falls considerably in temperature.

When the steam condenses, it is reduced to about $\frac{1}{1700}$ of its former volume, while the air with which it was mixed remains in the apparatus and occupies almost as much space as when it entered.

The diffusion of steam into a mass of air which is confined in the same pipes and is under the same pressure is very slow.

The diffusion of gases is greatly affected by the presence of dust. Dust tends to settle in obedience to gravitation, and thus carries down with it gases which cling to the particles of solid matter composing the dust.

COMPOSITION OF THE ATMOSPHERE.

1472. The atmosphere is composed of several bodies of gas which exist independently of each other. They are thoroughly mingled by diffusion, but they are not united or combined in any way. The principal gases in the atmosphere are oxygen, nitrogen, water vapor, or steam, and carbonic acid, the last forming a very small portion of the whole.

The weight and density of the oxygen and nitrogen are nearly equal; consequently, it is not practicable to separate them by mechanical means. Wherever the oxygen is permitted to go, the nitrogen will certainly accompany it, because no means are known by which it can be held back.

The chemical properties of these gases are very different. Oxygen supports combustion, and is required by all living things to sustain life.

In breathing air, nitrogen is taken into the lungs along with the oxygen, because it can not be avoided. It is not known to be of any use to animals, but it is absorbed from the air and converted into useful substances by several varieties of plants, such as peas and beans, and notably by the common red clover.

Nitrogen operates to retard combustion, mainly by absorbing heat.

Pure oxygen may be breathed with impunity, and persons may live in it for a short time without serious harm. But as the vital energy is so much greater than that to which the lungs are accustomed, a person breathing it would become feverish and intoxicated.

In the ordinary atmosphere the proportions of oxygen and nitrogen vary slightly at times, but not to any important extent. The average composition of one pound of dry air is:

Oxygen	0.2309 lb.
Nitrogen	0.7687 lb.
Carbonic acid	0.0004 lb.

Water will absorb more oxygen than nitrogen; consequently, the air which permeates a body of water contains a much larger percentage of oxygen than that in the atmosphere.

In the above statement of the composition of air, the weight of the water vapor, or steam, which always exists in the natural atmosphere is omitted, and the figures given are true only for air which is void of moisture.

HUMIDITY.

1473. The water vapor which pervades the atmosphere exists in the form of a gas independently of the oxygen and nitrogen, but being a compound gas its properties differ somewhat from those of a simple gas. Thus, it condenses into water at 212° under a pressure of 14.7 lb. per square inch, while oxygen and nitrogen become liquids only at extremely low temperatures and under enormous pressures.

But steam does not condense entirely and completely into water under atmospheric pressure at the temperature of 212°. A part of it remains in the gaseous condition as true steam, even though its pressure should fall below that of the atmosphere. Steam exists at all temperatures down to zero, and even many degrees below. Thus, at 20° below zero, and under an absolute pressure of .008 lb. per square inch, steam still exists.

Under natural conditions, the atmosphere is never free from the presence of steam, or vapor of water.

The absolute pressure of this steam is very low, but it forces its way into the space which is occupied by the other atmospheric gases, and increases the total tension of the atmosphere by the amount of its own pressure.

The aggregate tension of the gases which constitute the atmosphere is shown by the barometer, but no instrument has yet been devised which will show the actual tension of any single one of these gases; therefore, the pressure of the atmospheric steam can not be measured directly, except by apparatus which can not be conveniently used outside of the laboratory.

A cubic foot of air will admit or take up the same quantity of steam as a cubic foot of empty space. The weight of the steam will depend solely upon the temperature, provided that it does not become superheated. The temperature to be considered is that at which condensation begins.

1474. The *quantity* of steam should always be measured by its weight. It will be observed, upon inspection of the table of Properties of Saturated Steam, that the weight of a cubic foot of saturated steam increases with the temperature, while the weight of air decreases as the temperature rises, because the air is expanded. Steam will always have the weight given in the table, unless it is shut off from all communication with water and is superheated. The pressure and weight increase simultaneously, but at different rates; consequently, the pressure should not be taken as an index of the quantity of the steam.

The ratio between the quantity of vapor, or atmospheric steam, which is *actually* present in the air, and the *maximum* quantity which it could contain at the temperature and barometric pressure then prevailing, is called the **humidity** of the air.

1475. When the atmosphere contains the maximum quantity of steam that can exist at the temperature of the air, it is said to be **saturated** with moisture.

During fair weather the quantity actually present is much below the maximum which the temperature of the atmosphere would permit. When the maximum is reached, then the least diminution of temperature or barometric pressure will be followed by the condensation of a part of the vapor. The condensed vapor will be precipitated as dew or rain during summer weather, or as snow in winter time, and in very cold weather it will appear as hoar-frost.

MEASUREMENT OF HUMIDITY.

1476. There are many substances which absorb moisture from the atmosphere and which swell in volume in consequence. Many attempts have been made to utilize this property, to construct instruments which would indicate the density of the moisture in the air. Until recently none have been produced which were accurate or reliable. The most successful instrument of this kind is shown in Fig. 577. The indicator hand is attached to a metallic spiral which is filled with absorbent material. This material absorbs moisture from the air in proportion to the density of the atmospheric vapor, and gives it off again as the density decreases. The material swells in proportion to the amount of moisture which it holds, and thus the spiral which contains it is compelled to bend, like the Bourdon tube in a steam gauge.

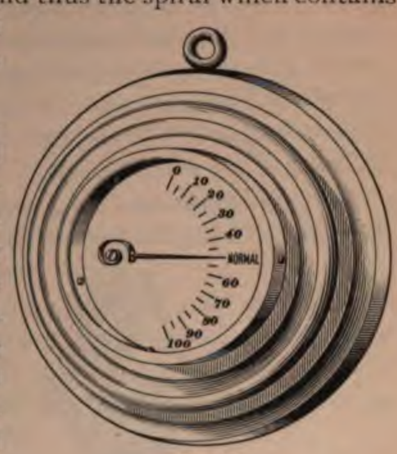

FIG. 577.

The humidity of the atmosphere may be measured by means of two thermometers, one of which is perfectly dry, and the other provided with a wet cloth over its bulb. The cloth is kept moist by a thread or wick leading from a small tank. If the air is not *saturated*, the water will evaporate from the cloth and thus cool the bulb. The rapidity of the evaporation depends upon the relative dryness of the air, and the depression of the thermometer indicates approximately the rate of evaporation from the cloth. This device is called the **wet and dry bulb thermometer.** The scale of humidity is arbitrary, and the operation of the instrument is not sufficiently accurate to be satisfactory.

The humidity of the atmosphere may be accurately measured by observing the temperature at which the contained moisture or vapor will condense. Having found the temperature at which condensation takes place, the pressure of the vapor per square inch and its weight per cubic foot may be found from Table 57.

1477. The weight of moisture which is said to be **absorbed** by a cubic foot of air is the weight of a cubic foot of vapor at the pressure and temperature thus found.

The instruments commonly used for this purpose are called **dew-point hygrometers.** They operate by gradually cooling a bulb or plate of black glass below the atmospheric temperature. As the temperature falls, a point will be reached when a deposit of dew begins to appear upon the glass. The formation of dew signifies that the atmospheric vapor which is actually present condenses at the temperature which the glass then possesses. Black glass is preferred, because it readily shows the slightest film of dew.

Two forms of hygrometers which are in common use, are shown in Figs. 578 and 579.

1478. Daniell's hygrometer is shown in Fig. 578. It consists of a glass tube *A* having a bulb at each end, as shown. The bulb *B* is made of black glass, and is partly filled with sulphuric ether. The bulb *D* is empty and is covered with muslin. A small mercurial thermometer *C* is enclosed in the tube *A*, and is so suspended that its bulb extends below the surface of the liquid ether. This thermometer indicates the temperature of the liquid in the bulb *B*. A second thermometer *E*, attached to the wooden stand, indicates the temperature of the surrounding air. To operate the instrument and obtain a deposit of dew upon the bulb *B*, a small quantity of ether is poured over the muslin on bulb *D*. The ether evaporates rapidly, and thus absorbs heat from the bulb and the ether vapor contained in the instrument. As the temperature falls, a point will be reached when a deposit of dew will appear upon the surface of the bulb *B*. The dew will remain there until the ether wholly evaporates from the muslin covering of *D* and the instrument begins to recover its normal temperature.

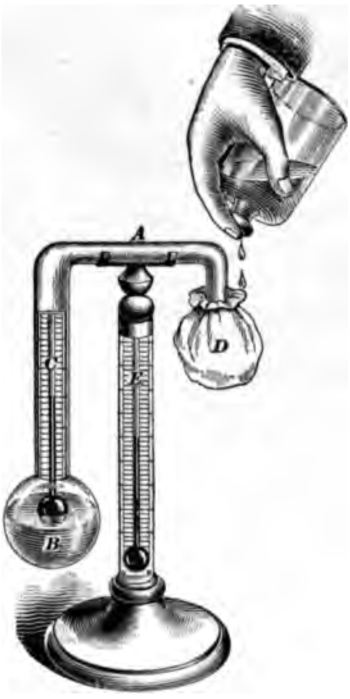

FIG. 578.

If too much ether is poured upon the cloth-covered bulb *D*, the instrument may be cooled to such an extent as to depress the thermometer *E* and cause it to give a false indication of the temperature of the atmosphere.

The temperature shown by the thermometer *C* at the exact moments when the dew appears and disappears must be carefully noted. If there is much difference in the first and second readings, the test should be repeated. When the test is properly made, the average of the two readings may be taken as the correct dew point.

1479. A **Dines' hygrometer** is shown in Fig. 579. It consists of a small metal box or chamber, which has a top plate *a* of thin black glass. The bulb of a thermometer *b* is placed close to the under side of the glass, but not in contact with it. The box is kept full of water by means of a pipe *c*, which extends to a small tank of ice water *d*. When the cock *e* is opened, the water flows through the box and escapes at the waste pipe *f*.

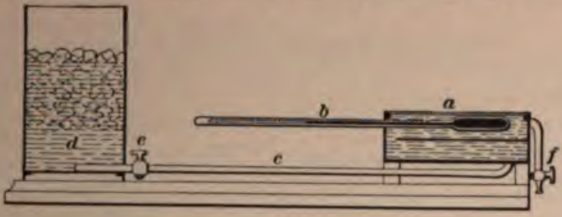

FIG. 579.

To ascertain the dew point, the box is first filled with water having about the same temperature as the air. Then ice water (or lumps of ice and water) is placed in the tank *d*; the cock *e* is then opened enough to permit a small stream of cold water to pass into the box and mingle with the water which it contains. When the water is cooled to the *dew point*, a deposit of dew appears on the surface of the glass *a*. The cock *e* is then closed and the box allowed to recover its normal temperature. As the temperature rises, the dew will vanish. The temperatures indicated by the thermometer *b* at the exact moments when the dew appears and disappears should be carefully noted, as with the Daniell instrument previously described. The temperature of the air should be measured by an independent thermometer.

To make a measurement of humidity, the instrument should be placed in a position where it will be free from the influence of any heating agency. The operator should take care that the warmth of his hands or breath does not affect the thermometers. Then use the following

Rule.—*Having found the dew point, as already explained, ascertain from Table 57 the weight of a cubic foot of vapor at that temperature; this divided by the weight of a cubic foot of vapor at the temperature of the atmosphere expresses the* **relative humidity.**

TABLE 57.

PROPERTIES OF AQUEOUS VAPOR.

Temperature, F°.	Pressure per Sq. In., Pounds.	Weight per Cu. Ft., Pounds.	Temperature, F°.	Pressure per Sq. In., Pounds.	Weight per Cu. Ft., Pounds.
— 30	.0049	.000017	50	.176	.00058
— 25	.0063	.000023	55	.212	.00069
— 20	.0088	.000030	60	.253	.00082
— 15	.0106	.000039	65	.302	.00097
— 10	.0135	.000050	70	.358	.00115
— 5	.0171	.000063	75	.425	.00135
0	.0216	.000079	80	.502	.00158
5	.0272	.000098	85	.589	.00183
10	.0340	.000121	90	.692	.00213
15	.0423	.000149	95	.809	.00247
20	.0525	.000181	100	.943	.00286
25	.0651	.000222	105	1.094	.00330
30	.0806	.000270	110	1.265	.00380
35	.0998	.000325	115	1.462	.00433
40	.1225	.000400	120	1.682	.00496
45	.1470	.000480	130	2.213	.00640

Example.—What is the relative humidity when the temperature of the atmosphere is 70° and the dew point is found to be at 45° ?

Solution.—From Table 57, the weight of 1 cubic foot of vapor at 45° is .00048 lb. The weight of 1 cubic foot at 70° is, from the same table, .00115. Hence, relative humidity $= .00048 \div .00115 = .417$, or 41.7 per cent. Ans.

MOISTENING AIR.

1480. It is very necessary that air which is to be breathed should contain a proper amount of moisture. If the air in a room is too dry, it will have an irritating effect upon the lungs of the person breathing it. The moisture which naturally exudes from the lungs and skin will be evaporated with undue rapidity. This interferes with the proper operation of the lungs, and respiration under these circumstances is very imperfect.

The unnatural dryness of the skin gives rise to considerable nervous irritation, which, if long continued, will seriously affect the general health.

It has been found by observation and experiment that a degree of humidity of from 50 to 70 per cent. should be maintained in dwellings, offices, and audience rooms to secure health and comfort. The air in such rooms is usually maintained at a temperature of 65° to 70° F., therefore the *dew point*, as measured by the hygrometer, should be about 55°.

If the dew point is too high, there will be an unpleasant feeling of dampness in the air; the window panes will drip with moisture, and there will be a deposit of dew on all the objects in the room which have a temperature lower than the normal.

If there is a great difference in temperature in the upper and lower parts of the room, the humidity should be adjusted to suit the zone in which the people breathe.

1481. The amount of water which must be evaporated and added to the air supply to maintain any certain degree of humidity may be found as follows:

Rule.—*Ascertain the weight of moisture in the air before it is heated, and compute the weight of moisture required to produce the desired degree of humidity in the same weight of air at the temperature at which it is to be used; the difference between the quantities of moisture thus found will be the amount of moisture to be supplied.*

EXAMPLE.—A certain room is supplied with air having a temperature at the registers of 120°, at the rate of 300 cu. ft. per min. The temperature of the room is to be maintained at 70°, and the humidity at 70 per cent. The temperature of the air before entering the heater is 45°, and its humidity is also 70 per cent. What weight of moisture must be supplied to the air current to secure the desired humidity in the room?

SOLUTION.—It is necessary to know the volumes of the air at the time it is used and before it enters the heater, and these must be computed from the volume and temperature at the register as given. The original volume is 300 cu. ft., and the original temperature is 120° (580°, absolute). Applying rule, Art. **1424,** to find the volume at 70° (530°, absolute),

$$V_1 = \frac{V\,T_1}{T} = \frac{300 \times 530}{580} = 274.1 \text{ cu. ft.},$$

and at 45° (505°, absolute),

$$V_1 = \frac{V\,T_1}{T} = \frac{300 \times 505}{580} = 261.2 \text{ cu. ft.}$$

Thus, at the beginning we have 261.2 cu. ft. of cold air at 70 per cent. humidity. The weight of that volume of vapor at 45° is, from Table 57, $261.2 \times .00048 = .1254$ lb., and 70 per cent. of this equals $.1254 \times .70 = .08778$ lb., which is the weight of moisture originally contained in the air.

The air when used will have a volume of 274.1 cu. ft. and a temperature of 70°. The weight of an equal volume of vapor at 70° is $274.1 \times .00115 = .3152$ lb. The humidity is required to be 70 per cent.; therefore, the total moisture required will be $.3152 \times .70 = .22064$ lb.

Then, $.22064 - .08778 = .13286$ lb., which is the amount of moisture per minute that must be added to the air current. Ans.

1482. It will be observed from the foregoing example that the quantity of water required to maintain any certain degree of humidity is much greater for warm air than for cold. The amount increases faster than the temperature.

The table shows that the increase of moisture per cubic foot for a rise in temperature from

−10° to 0° is .000029 lb.
30° to 40° is .000130 lb.
80° to 90° is .000550 lb.

Thus, the increase between 80° and 90° is nearly 19 times as much as between −10° and 0°.

Inasmuch as the space into which water evaporates is usually occupied by air, and as the temperature of the air determines the temperature of the vapor, it is natural to speak of the *capacity of the air for vapor*. This is really a misleading expression, like many others inherited by science from the obscurity of earlier years. The idea that air absorbs moisture as a sponge absorbs water is entirely erroneous. The vapor forces its way into space solely by virtue of its expansive power. The amount which will enter into any given space depends only upon its own temperature, and it is not affected by the presence or absence of other gases in the same space.

The terms commonly used to describe the phenomena of atmospheric vapor are so firmly fixed in our language that they can not be easily changed. Much obscurity and perplexity may be avoided, however, by fixing the real meaning of the terms clearly in the mind.

EVAPORATION AND DRYING.

1483. The process of evaporation is used in the arts for increasing the density of liquids by **boiling down,** for drying wet materials, and for cooling purposes.

The vaporization of the liquid may be accomplished by adding more heat to it, or by lessening or removing the atmospheric pressure upon it. If heat is added to a body of water, the pressure of the vapor or steam which it will give off will increase as the temperature increases. The increase of tension will enable the vapor to disperse with greater freedom into the atmosphere. When a temperature of 212° is reached, the tension equals that of all the other atmospheric gases, and the steam pushes them aside and disperses into space with the utmost freedom. The water will then pass into vapor as rapidly as the heat required for vaporization can be supplied to it. If the atmospheric pressure is reduced, the temperature at which the water will pass into steam of equal pressure and freely disperse will be lowered correspondingly. At a pressure of 1 pound per square inch, absolute, the water will boil at about 102°.

The temperature of the liquid can not be increased above the boiling point, and the boiling point is fixed mainly by the pressure upon the surface of the liquid. This fact is of the greatest importance in the manufacture of sugar, condensed milk, and in all operations of *boiling down*, or concentrating, liquids. The flavor of the material, which would be destroyed by a temperature of 212°, can be retained perfectly if the cooking be done in a partial vacuum. The vacuum pans which are used in sugar making and other manufactures are operated upon these principles.

If a body of warm air of ordinary pressure and humidity be brought into contact with water, evaporation will begin at once. The vaporization of the water will continue until the air attains the maximum of humidity, or becomes *saturated*, as before explained. The rapidity of evaporation will be proportional to the difference between the actual humidity of the air and the possible humidity.

If the vapor is removed as rapidly as it is formed, the evaporation will be continuous and uniform. This may be accomplished by supplying fresh air in a continuous current, as in ordinary drying apparatus, or by condensing the vapor by means of an air pump and surface condenser, as in vacuum pans, etc.

Air may be partially dried by cooling it to a low temperature. The vapor accompanying it will be condensed and precipitated as water, and when the air is afterwards warmed it will be correspondingly dry.

1484. The efficiency of a drying apparatus which uses hot air as the drying medium will depend upon several factors, as follows:

First. The dryness of the air before it is heated.

Second. The degree of heat which is given to the air.

Third. The amount of surface of wet material from which evaporation can readily take place.

Fourth. The volume of the air current.

Fifth. The thorough distribution of the fresh dry air over the evaporating surfaces.

Sixth. The promptness with which the moistened air is removed.

If the air is compelled to travel a long distance over wet surfaces, it will evaporate moisture freely during the first part of its course, less in the middle, and almost none at the end of the course. It is, therefore, advisable that the air currents be so arranged that none of them are obliged to travel over a course of undue length.

1485. The drying rooms of laundries are usually deficient in circulation of air, although well supplied with heat. Heat alone can not dry the clothes; the moist air must be removed as fast as it is moistened. The humidity of the outgoing air should not be allowed to approach *saturation*, but should be kept as low as practicable. If the supply of air is abundant, less heat will be required and the drying operation will be more satisfactory. The disagreeable odor of clothes which are dried in ordinary laundry apparatus is largely due to the excessive and unnatural heat, and to the extreme humidity of the air within the apparatus. The heat and moisture combined develop odors from the materials composing the clothing which do not appear under ordinary temperatures; and the supply of air is so deficient that these odors are not thoroughly removed. The superiority of the mode of drying clothes in the open air and sunlight is due to the moderate heat of the sun's rays and the abundant supply of fresh air of moderate humidity.

The effectiveness of the drying apparatus will depend to a considerable degree upon the thoroughness with which the material is spread out and exposed to the air currents.

PRINCIPLES OF HEATING AND VENTILATION.

(CONTINUED.)

CHEMICAL ELEMENTS.

LAWS OF CHEMICAL COMBINATIONS.

1486. Elements and Compounds.—Every body and every mass of matter is either an **element,** a **compound,** or a **mixture.** Iron, silver, sulphur, and oxygen are elements; water, wood, lime, and carbonic acid are compounds.

1487. A compound may be decomposed or divided into separate substances. For example, if an electric current is passed through water, the water slowly disappears and two gases are formed. These gases are entirely unlike, and neither resembles the water from which it was produced. Likewise, lime can be divided into two other substances, calcium and oxygen. Any substance which can thus be decomposed or divided into other substances is called a **compound.**

1488. There are substances, however, which have never been decomposed into other substances. By no known process can sulphur be separated into other substances; likewise with iron, gold, arsenic, and many other substances. Substances which have never been decomposed are called **elements.**

The elements which will be considered in this subject are the following:

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Elements.	Symbols.
Hydrogen	H
Oxygen	O
Nitrogen	N
Carbon	C
Sulphur	S
Chlorine	Cl

In referring to an element, it is customary to simply use the symbol, which is usually the first letter of the name. Thus H stands for hydrogen, C for carbon, etc.

1489. Chemical Combination.—When two or more elements are brought into contact under favorable circumstances, they will combine and form a new substance unlike either of the elements. The nature of the compound will generally be very different from the nature of the elements, so far at least as it affects our senses. For example, hydrogen, an exceedingly light gas, will burn in the air with a light blue flame. This burning is a form of chemical combination, in which the hydrogen unites with another gas, the oxygen of the air, and forms water, a substance with which we are all familiar.

Chemical combination produces heat; chemical separation, on the other hand, absorbs heat. Thus, if carbon and oxygen are brought together at high temperature, they will combine and form carbon dioxide; hydrogen and oxygen combine to form water; hydrogen, nitrogen, and oxygen, when combined in certain proportions, form nitric acid; a given volume of nitrogen and three times that volume of hydrogen combine and form ammonia, a gas which differs greatly from both nitrogen and hydrogen. In each of these combinations a certain amount of heat is produced; to separate the elements again an amount of heat will be absorbed exactly equal to that produced by their combination.

1490. It is supposed that each molecule of an element, such as hydrogen or oxygen, is composed of two atoms. It is further supposed by chemists that equal volumes of all gases, whether simple or compound, contain the same number of molecules. Thus, a cubic foot of hydrogen, a cubic foot of air, a cubic foot of steam, all contain the same number of molecules.

Suppose, now, that a cubic foot of hydrogen gas is allowed to come in contact with a cubic foot of chlorine gas. The mixture is exposed to heat or light, and the gases combine. The process of combination is explained as follows: There is a certain attraction or affinity between the hydrogen and the chlorine atoms. Under the influence of heat or light, this attraction becomes so strong that the two atoms composing the molecule of hydrogen are torn apart. Likewise, the atoms composing a molecule of chlorine separate. Each atom of chlorine seizes upon an atom of hydrogen and forms a molecule of an entirely new gas, viz., hydrochloric acid gas. Since each atom of chlorine takes one atom of hydrogen, it is plain that the number of molecules of each gas must be the same. In other words, a cubic foot of chlorine requires a cubic foot of hydrogen to combine with it; these gases can not be made to combine in any other proportion. For example, if three cubic feet of chlorine were placed in contact with two cubic feet of hydrogen, four cubic feet of hydrochloric acid gas would be formed, and the extra cubic foot would still remain chlorine. The symbol for hydrochloric acid gas is HCl.

1491. Suppose, now, that hydrogen and oxygen are placed in contact and heated; they will combine and form steam (or water). But it will be found that each atom of oxygen seizes two atoms of hydrogen to form a molecule of water, and, therefore, the volume of hydrogen must be double the volume of the oxygen with which it combines. This is shown by the symbol for water, which is H_2O; that is, two parts of hydrogen to one of oxygen. Similarly, the symbol for ammonia is NH_3; that is, three parts of hydrogen to one of nitrogen. Again, hydrogen and carbon form a compound; each atom of carbon seizes four atoms of hydrogen

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and forms a molecule of marsh gas. The symbol for marsh gas is, therefore, CH_4.

The symbol of any compound indicates how the atoms of the elements combine to form the compound. Thus, the symbol for water, H_2O, shows that two atoms of hydrogen and one of oxygen unite to form a molecule of water. The symbol H_2SO_4 (sulphuric acid) shows that a molecule of the sulphuric acid contains two atoms of hydrogen, one of sulphur, and four of oxygen.

1492. Combination by Weight.—One cubic foot of hydrogen combines with just one cubic foot of chlorine. Upon weighing each gas, it is found that the cubic foot of chlorine weighs 35.5 times as much as the cubic foot of hydrogen. A cubic foot of oxygen weighs 16 times as much as a cubic foot of hydrogen.

It has been stated that equal volumes of gases contain the same number of molecules. Therefore, a cubic foot of oxygen must contain the same number of atoms as a cubic foot of hydrogen. Now, since the former weighs 16 times as much as the latter, it follows that an atom of oxygen weighs 16 times as much as an atom of hydrogen. Similarly an atom of chlorine weighs 35.5 times as much as an atom of hydrogen. This ratio between the weight of an atom of any element and the weight of an atom of hydrogen is called the **atomic weight,** or the **chemical equivalent,** of the element. The atomic weight of any element (or compound) may be found by dividing the weight of a given volume, say a cubic foot, of the element, when in a gaseous state, by the weight of a cubic foot of hydrogen. The atomic weight is, therefore, about the same thing as specific gravity, hydrogen being the base of comparison instead of water or air. There are over 60 elements, and each of them has a certain fixed proportion in which it combines with other elements or with parts of compounds; this proportion is the atomic weight of the element or some simple multiple of this.

1493. The atomic weights of the elements named above are as follows:

Hydrogen (H)	1.0
Oxygen (O)	16.0
Nitrogen (N)	14.0
Carbon (C)	12.0
Sulphur (S)	32.0
Chlorine (Cl)	35.5

By the aid of these atomic weights the composition of any substance by weight can be found when its symbol is known. Take water, the symbol for which is H_2O; that is, there are two atoms of H to one of O. Multiply the number of atoms of each by the atomic weight of the atom. Thus,

$2 \times 1 = 2$ parts by weight of hydrogen.
$1 \times 16 = \underline{16}$ parts by weight of oxygen.
18 parts by weight of water.

Water, then, is composed of $\frac{2}{18} = 11.11$ per cent. of hydrogen, and $\frac{16}{18} = 88.89$ per cent. of oxygen.

As another example, take carbon dioxide, CO_2. We have

1 atom of C $\times$ atomic weight, $12 = 12$ parts by weight of C.
2 atoms of O $\times$ atomic weight, $16 = \underline{32}$ parts by weight of O.
44 parts by weight of CO_2.

Hence, CO_2 contains $\frac{12}{44} = 27.27$ per cent. carbon and $\frac{32}{44} = 72.73$ per cent. oxygen. From these examples it is plain that the atomic weight of water is 18, and of carbon dioxide 44.

1494. Mixtures.—Two or more elementary substances may be mixed together and yet not combine to form a new substance. They are then said to form a **mixture.** The mixture has the properties of the elements composing it. The most familiar example of a mixture is ordinary air. It is composed of oxygen and nitrogen, 23 parts by weight of the former to 77 parts by weight of the latter. The two gases are not combined chemically; they are simply mixed.

COMBUSTION.

1495. By **combustion** is meant the phenomenon ordinarily called burning, as when a piece of wood or coal or a candle is burning. In reality, *combustion is a very rapid chemical combination* in which the most prominent part of the air—the oxygen—unites with a combustible material, producing heat and light at the same time. Oxygen has a great attraction for nearly all the other elements; an atom of oxygen is ready to combine with almost any substance with which it comes in contact. For carbon, oxygen has a particular liking, and whenever these two elements come in contact at a sufficiently high temperature (at their *igniting* temperature) they combine with great rapidity. The combustion of coal in the furnace of a boiler is of this nature. The temperature of the furnace is raised by kindling the fire, and then the carbon of the coal begins to combine with oxygen taken from the air. The combination is so rapid and violent that a great quantity of heat is given out.

1496. The elements which enter into combustion are oxygen, carbon, and hydrogen. Coal, wood, and other fuels are composed almost entirely of these three elements. *Combustion is, therefore, the rapid chemical combination of oxygen with either carbon, or hydrogen, or both.*

We have seen that when carbon and oxygen combine they form CO_2, or carbon dioxide; when hydrogen and oxygen combine they form water, H_2O. These are called the **products of combustion.** When, as is ordinarily the case, the oxygen is obtained from the air, the nitrogen of the air passes into the furnace along with the oxygen. It takes no part in the combustion, and passes off up the chimney with the CO_2. Hence, nitrogen is also a product of combustion in air.

1497. It has been shown that CO_2 is composed of 12 parts by weight of carbon to 32 of oxygen. Hence, to burn a pound of carbon requires $\frac{32}{12} = 2\frac{2}{3}$ pounds of oxygen. If the oxygen is taken from the air, it will take $2\frac{2}{3} \div .23 = 11.6$ pounds of air to supply the $2\frac{2}{3}$ pounds of oxygen. This is because only 23 per cent. of air is oxygen. The combustion of a pound of carbon may be represented as follows:

	Elements.	Products.
1 lb. carbon....	1 lb. carbon	3.67 lb. CO_2
11.6 lb. air........	2.67 lb. oxygen	
	8.93 lb. nitrogen...	8.93 lb. nitrogen
12.6	12.6	12.6

That is, one pound of carbon requires 11.6 pounds of air for complete combustion. Of this air, 2.67 pounds are oxygen, and this combines with the pound of carbon, forming 3.67 pounds of carbon dioxide. The 8.93 pounds of nitrogen contained in the air pass off with the CO_2 as a product of combustion.

1498. Next consider the complete combustion of a pound of hydrogen. The product of the combustion is water, H_2O. It has been shown that H_2O is composed of two parts by weight of hydrogen to 16 parts of oxygen. Hence, one pound of H requires $\frac{16}{2} = 8$ pounds of O to unite with it. The air required to furnish 8 pounds of O is $8 \div .23 = 34.8$ pounds. The process of combustion is, therefore, as follows:

	Elements.	Products.
1 lb. hydrogen...	1 lb. hydrogen	9 lb. water (H_2O)
34.8 lb. air.........	8 lb. oxygen	
	26.8 lb. nitrogen	26.8 lb. nitrogen
35.8	35.8	35.8

1499. There is one other case that may occur—the combustion of carbon may not be complete. If insufficient air or oxygen is supplied to the burning carbon it is possible for the carbon and oxygen to form another gas, carbon monoxide, or CO, instead of carbon dioxide CO_2.

The combustion of a pound of carbon to form CO requires, of course, only half of the oxygen that would be necessary to form CO_2. This is because in the gas CO one atom of carbon seizes one atom of oxygen instead of two. To burn a pound of carbon to CO_2 requires 11.6 pounds of air. To burn it to CO would, therefore, require but 5.8 pounds of air.

The quantities of air required for combustion are shown in the following scheme:

One Pound.	Air at 62°.	Product of Combustion.
Hydrogen.....	34.8 lb., or 457 cu. ft.	Water. Nitrogen.
Carbon burned to CO_2......	11.6 lb., or 152 cu. ft.	Carbon dioxide. Nitrogen.
Carbon burned to CO.......	5.8 lb., or 76 cu. ft.	Carbon monoxide. Nitrogen.

1500. The fuels in common use are composed chiefly of carbon, with sometimes a small percentage of hydrogen, oxygen, and incombustible matter called ash. When the percentages of carbon and hydrogen are known, the air required for the combustion of a pound of the fuel is easily found. For example, suppose a certain coal is 90% carbon and 10% hydrogen. To burn the carbon requires $152 \times \frac{90}{100} = 136.8$ cu. ft. of air; to burn the hydrogen requires $457 \times \frac{10}{100} = 45.7$ cu. ft. of air. Hence, to burn a pound of fuel requires $136.8 + 45.7 = 182.5$ cubic feet of air.

Let C = the number of parts of carbon contained in 100 parts of a given fuel.

H = the number of parts of hydrogen contained in 100 parts of the same fuel.

A = the number of cubic feet of air required for the combustion of a pound of the given fuel.

B = the heat of combustion of a pound of the fuel in B. T. U.

W = the number of pounds of water at 212° evaporated by a pound of the above fuel.

Then,
$$A = 152 \times \frac{C}{100} + 457 \times \frac{H}{100},$$

or,
$$A = 1.52\,(C + 3\,H), \text{ very nearly.}$$

Whence we have the following rule:

Rule.—*To find the air required to burn a given fuel: To the carbon contained in the fuel add three times the hydrogen, multiply the sum by 1.52, and the result will be the air required in cubic feet at a temperature of 62° F.*

Example.—The composition of a certain kind of coal is as follows:

Carbon	84 parts.
Hydrogen	5 parts.
Oxygen	7 parts.
Ash	4 parts.
	100

Find the quantity of air required to completely burn a pound of this fuel.

Solution.—According to the above rule,

$$A = 1.52 \times (C + 3H) = 1.52 \times (84 + 3 \times 5) = 150.48 \text{ cu. ft.} \quad \text{Ans.}$$

When the fuel already contains oxygen, a little less air is required to burn it; if it contains sulphur, a little more air will be required than given by the above rule. In either case the difference is very slight. It will be found that a pound of coal requires practically the same amount of air, whether it be anthracite or bituminous. Roughly speaking, it requires about 12 pounds, or 160 cubic feet, of air to burn a pound of carbon or coal. If less air is supplied, the combustion will be imperfect; that is, the carbon burns to CO, instead of to CO_2.

1501. Rapidity of Combustion.—The process by which oxygen combines with other substances is designated by the general term **oxidation.** This process proceeds with varying degrees of rapidity, according to circumstances. Slow oxidation is sometimes described as **slow combustion,** but the term *combustion* is generally understood to mean rapid oxidation, which causes the material to glow with light and heat, or which produces flame.

The temperature at which free combustion will begin differs considerably in various substances, and it is very much affected by changes in the pressure of the oxygen, becoming lower as the pressure is increased. This critical temperature at which combustion begins is called the **point of ignition.**

1502. The fact that the point of ignition can be lowered by pressure is utilized, in a certain variety of gas engines, to ignite the charges of mixed air and gas. The mixture is forced into a chamber which is maintained at a temperature slightly lower than that required to ignite the gas when it is at atmospheric pressure. As the charge is compressed by the motion of the piston, the pressure rises, and the point of ignition falls until it reaches the temperature of the chamber; the gas then ignites and explodes as desired.

The point of ignition may, in some instances, be lowered by compression to ordinary atmospheric temperature. Thus, if a mixture of oxygen and hydrogen be highly compressed in a receiver, it is liable to explode with great violence, even if care is taken to compress slowly and keep the receiver cool.

1503. The term **spontaneous combustion** is applied to those cases in which ignition takes place without the direct application of heat or pressure. It may occur in several ways. Thus, when a combustible body is slowly oxidized and the heat evolved is prevented from escaping, the temperature of the body will gradually rise, and the oxidation will increase in rapidity, and the evolution of heat will proceed faster, until finally the temperature reaches the point of ignition, when the body takes fire and burns.

This is liable to occur in a mass of oily cotton waste, or in a pile of closely packed hay or straw which is slightly moist. Large heaps of coal refuse, or culm, frequently take fire from this cause, especially if the refuse contains much sulphur.

1504. **Spontaneous ignition** is also caused by rapid absorption of oxygen from the air. Thus, freshly made charcoal is destitute of oxygen, and when it is exposed to the air, it will absorb oxygen so rapidly that it is very liable to take fire. This may be prevented by moistening the charcoal with water.

A pipe containing steam at ordinary pressure will cause spontaneous ignition of wood which is very close to it, or in contact with it. As the moisture is driven out of the wood by the heat, oxygen from the air takes its place, and the woody substance becomes oxidized to a certain extent. The change in the wood is increased by each repetition of the process, or by steadily applied heat; and the wood becomes brown in color, then begins to char, and, finally, when the heat is unusually high, or the change from cold to hot is unusually quick, it may ignite and burst into flame.

1505. Hydrogen gas may be ignited by rapid absorption. Thus, if a jet of hydrogen be projected upon a mass of platinum which is in a porous or spongy condition, the metal will absorb many times its own volume of the gas. The hydrogen is not combined with the metal, but is merely condensed and retained within its pores. The hydrogen is compressed into a small fraction of its original volume; consequently, it develops a considerable amount of heat, precisely as it would do if it were compressed by a pump to the same extent and in the same time. The metal quickly becomes red hot and the gas is ignited.

1506. The rate at which the combustion of any given substance will proceed, depends upon several conditions, as follows:

1. The pressure of the oxygen, or of the air which contains it.
2. The amount of heat which is required to raise the combustible to the point of ignition.
3. The extent of hot surface which is exposed to oxygen.
4. The diffusion of the oxygen among the combustible material.
5. The prompt removal of the products of combustion.

All combustibles will burn more rapidly in compressed air than in the atmosphere, because of the increased *pressure* of the oxygen. Combustion will be still more rapid if carried on in pure oxygen. The pressure of the oxygen in the ordinary atmosphere is about 3.08 lb. per square inch, but the pure gas when contained in a jar, without compression, has a pressure equal to that of the atmosphere, or 14.7 lb. per square inch—nearly 5 times as much.

The nitrogen contained in the air is incombustible, and it retards combustion by its presence, thus obstructing the contact of the oxygen with the surface of the burning materials. The effect of removing the nitrogen and at the same time increasing the pressure of the oxygen may be shown by the following experiment:

If a piece of red hot iron be exposed to the air it will oxidize, but will not burn; but if it is plunged into a jar of oxygen, it will take fire and burn with great brilliancy.

1507. In burning coal and similar substances, *the carbon must be heated to incandescence* before the oxygen can combine with it with sufficient rapidity to maintain the fire. The heat developed is partly lost by radiation, and the remainder is spent in warming the oxygen consumed and the nitrogen which accompanies it, and in raising the temperature of the carbon up to incandescence. This latter requirement is the one which usually determines the rate of combustion. In burning light oils, the amount of heat consumed in raising their temperature to the point of ignition is very small; consequently, they burn with great rapidity. But, in the case of hard coal, the amount of heat thus consumed is relatively large, and the combustion, therefore, proceeds slowly. If the loss of heat by radiation be diminished, then the amount available for heating the fuel will be greater, and the combustion will be intensified. In practice this is accomplished by lining the combustion chamber with firebrick.

Combustion proceeds only at the *surface* of a lump of coal, although the interior of the lump may be incandescent. This is because the oxygen necessary for combustion can be obtained only upon the outer surfaces, where the fuel is in contact with the air.

Combustion is not *instantaneous* in any case, because a measurable amount of time is always required to elevate the temperature of the materials to the point of ignition, and

explosion differs from ordinary combustion mainly in the amount of time occupied by the process of combination.

If the interior parts of a lump of combustible material could be plentifully supplied with oxygen, the combination would take place throughout the whole mass as soon as the temperature became high enough. This is accomplished, in the case of gunpowder, by mixing the carbon, in the form of powdered charcoal, with other materials which are rich in oxygen. When combination begins, it spreads very rapidly throughout the whole mass, and the combustion is so extensive and rapid that the result is an explosion.

If the carbon, in the shape of fine dust, is diffused throughout a mass of air, it will burn when ignited with explosive rapidity, because each particle is surrounded with sufficient oxygen for combustion, and the whole mass will be burned in about the same time that is required to burn a single particle of the dust.

Similarly, if a quantity of combustible gas or oil vapor be diffused throughout a body of air, it will burn with explosive rapidity. The amount of heat thus suddenly set free is very great, and the consequent expansion of the air and gas is so sudden and extensive that the result is an explosion. This mode of burning fuel is employed in gas and oil engines.

1508. Heat of Combustion.—The quantities of heat produced by the complete combustion of the elements composing the fuels have been found by experiment. They are as follows:

Hydrogen	62,000 B. T. U. per pound.
Carbon burned to CO_2	14,500 B. T. U. per pound.
Carbon burned to CO	4,400 B. T. U. per pound.

Then, $$B = 14{,}500 \times \frac{C}{100} + 62{,}000 \times \frac{H}{100},$$

or $$B = 145\,C + 620\,H,$$

giving us the following rule:

Rule.—*To find the heat of combustion of a pound of fuel, multiply the percentage of carbon by 145, and the percentage* *of hydrogen by 620. Add the products, and the sum will be the required heat of combustion in B. T. U.*

EXAMPLE.—A certain kind of coal has the following composition:

Carbon	76.5 parts.
Hydrogen	4.4 parts.
Oxygen	3.0 parts.
Nitrogen	1.1 parts.
Ash	15.0 parts.
	100.0

How many B. T. U. will be produced by the combustion of a pound of this coal?

SOLUTION.—According to the rule just given,
$B = 145\,C + 620\,H = 145 \times 76.5 + 620 \times 4.4 = 13{,}820.5$ B. T. U. Ans.

1509. From the *steam table* it is found that to change a pound of water at 212° into steam at 212° requires 966 + B. T. U.; hence, the following rule:

Rule.—*To find the number of pounds of water evaporated at 212° by a pound of fuel, divide the heat of combustion of the fuel by 966;*

or,
$$W = \frac{B}{966}.$$

EXAMPLE.—How many pounds of water at 212° can be evaporated by a pound of the coal of the last example?

SOLUTION.—The heat produced by the combustion is 13,820.5 B. T. U.

$$13{,}820.5 + 966 = 14.3 \text{ lb. Ans.}$$

1510. Temperature of Combustion.—The theoretical temperature of the combustion of a given fuel can easily be calculated. Making no allowance for losses of heat, and supposing just enough air is furnished for the combustion, burning carbon should have a temperature of about 4,940° above zero; burning hydrogen should have a temperature of about 5,800° above zero. In practice, these temperatures are never attained, on account of the losses of heat. Usually, the quantity of air admitted to the furnace is from 50 to 100 per cent. more than is theoretically necessary for the combustion. This extra quantity of air enters at a temperature of 60° or 70°, and escapes up the chimney at a temperature of from 400° to 600°. A large quantity of heat is thus wasted, and the temperature of the fire is greatly lowered. Where the fire is outside of the boiler, and the furnace is surrounded by brickwork, the furnace temperature may be 2,500° or 3,000°; but when the furnace is inside the boiler and surrounded on all sides by water, the temperature rarely rises above 2,000°, and is usually less. A high temperature is, of course, desirable, since the water of the boiler will take up heat much faster at high than at low temperatures.

1511. Conditions Required for Economical Combustion.—The chief consideration is the air supply. It is not possible to obtain perfect combustion with the theoretical quantity of air; viz., 12 pounds, or 160 cubic feet, per pound of coal. This is because the air has to pass through the thick bed of coal, and it does not, therefore, come in close enough contact with the burning surface to insure perfect combustion. It is usually estimated that about 24 pounds of air are required with ordinary chimney draft, and 18 pounds with forced draft, for each pound of coal burned. If more air is used than is actually necessary, the extra amount simply carries heat from the furnace to the chimney. On the other hand, if too little air is admitted to the furnace, part of the carbon burns to CO instead of CO_2. It has been stated that the combustion of carbon to CO gives out but 4,400 B T. U. per pound. Here, then, is a loss of $14,500 - 4,400 = 10,100$ B. T. U. for each pound of carbon burned. Hence, the admission of either too much or too little air results in loss of efficiency.

1512. It is a general law that the excess of air required to produce the most economical results is inversely as the rate of combustion. In boilers that burn from 2 to 4 pounds of coal per square foot of grate surface per hour, the excess of air is 100 per cent. When the rate of combustion is from 10 to 16 pounds of coal per square foot of grate surface per hour, the excess is only 25 to 50 per cent.; finally, when the rate of combustion is over 20 pounds per square foot of grate per hour, the excess of air need be only about 10 per cent.

A common and serious source of loss is the escape of combustible gases from the heated coal. Most varieties of bituminous coal contain *hydrocarbons*. These are gases composed of carbon and hydrogen, such as marsh gas, common lighting gas, olefiant gas, and others. The carbon contained in these gases may be one-third or more of all the carbon contained in the coal.

When coal of this nature is thrown into the furnace, it becomes heated; but before it really begins to burn these gases are driven off, and unless some means are provided to burn them, they escape up the chimney. To burn these hydrocarbons it is necessary to admit air into the furnace *above* the fire, either through the furnace front or through the bridge wall.

1513. The most economical rate of combustion and the proper quantity of air to be admitted to the furnace can only be determined by experiment. The conditions of highest economy will in general be different for the different types of boilers and furnaces.

The amount of air actually required to burn coal depends in practice upon the *intensity* of the fire. The entering air must be heated to a proper degree before combination will take place with the incandescent fuel. If combustion is slow and the temperature of the fire is comparatively low, only a part of the air will be heated sufficiently to combine freely with the hot carbon, and the remainder will pass through the fire at a temperature which is too low to be of any use.

If the rate of combustion is increased, the fire will be hotter, and a larger percentage of air will attain the temperature necessary for combination. If the fire is hot enough to heat the entire quantity of air to the same temperature as the incandescent fuel, then the theoretical quantity of air will be sufficient for perfect combustion.

It is not practicable, however, to heat the air to that temperature in the brief time during which it passes through the fuel.

The quantity of air required in practice to properly burn coal at different rates of combustion, per square foot of grate surface per hour, is about as follows:

TABLE 58.

Rate of Combustion per Sq. Ft. of Grate; Lb. of Coal per Hour.	Air Required per lb. of Coal.	
	Weight, Pounds.	Volume at 62°, Cu. Ft.
4	23.2	304.85
8	20.2	265.45
12	17.5	230.00
16	15.1	198.43
20	13.0	170.83

There is little or no difference in the amount of air required per pound to burn anthracite or bituminous coal.

EXAMPLES FOR PRACTICE.

1. How many pounds of air will be required for the perfect combustion of 7 lb. of carbon? Ans. 81.2 lb.

2. A fuel is 88% carbon and 12% hydrogen. How many cubic feet of air are required for complete combustion of a pound?

Ans. 188.48 cu. ft.

3. (*a*) How many B. T. U. would the combustion of the pound of coal of Example 2 give out? (*b*) How many pounds of water at 212° would a pound of this fuel evaporate?

Ans. (*a*) 20,200 B. T. U.
(*b*) 20.9 lb.

4. The chemical symbol of the product of combustion of sulphur with oxygen is SO_2 (sulphurous oxide). What is the composition of this gas by weight?

Ans. Sulphur 50%.
Oxygen 50%.

5. Assume that, with ordinary draft, double the theoretical quantity of air is used to burn a fuel. Under these circumstances, how many cubic feet of air would be required to burn 115 pounds of coal, the chemical composition being H, 5 parts; C, 90 parts; O, 3 parts, and ash, 2 parts; total, 100 parts? Ans. 36,708 cu. ft.

SMOKE.

1514. All varieties of coal contain more or less volatile matter, which is given off before actual combustion begins. The amount given off by anthracite is so small that it usually escapes notice, but in bituminous coal the volatile matter constitutes from 15 to 30 per cent. of the total weight.

This volatile matter largely consists of carbon compounds, which are vaporized before the coal becomes hot enough to burn. These compounds exude from the coal as it grows hot, and, if not properly taken care of, they will pass off into the chimney in the form of dense black smoke.

Smoke is, therefore, a direct waste of fuel. When it becomes cooled, the carbon is precipitated in the form of soft, sticky dust called **soot.** This is deposited upon the inner surfaces of the boiler walls, the tubes, and also the flues and chimney, and thus adds greatly to the labor of cleaning.

1515. Usually the production of smoke is not due to a lack of air, but to a *lack of heat.* The volatile matters are discharged into the chimney before they can be heated to the point of ignition. Smoke can be prevented by any device which will promptly heat these volatile matters and ignite them. This is accomplished in many cases by passing them over highly heated brickwork.

Even if a furnace is working properly, it is likely to smoke as soon as the fire door is opened, because the great volume of cold air which then rushes in chills the volatile matters below the point of ignition.

1516. To avoid this trouble and to lessen the labor of feeding and cleaning the fire, **mechanical stokers** are sometimes employed. This is often accomplished by forcing the fresh coal in at the bottom of the fire, instead of spreading it upon the top. By this means all of the smoke and gas which is evolved is compelled to pass upwards through the incandescent fuel, and is thus ignited and burned.

1517. **Down-draft furnaces** are usually constructed with a grate of "water bars," and, as the name implies, the air passes through the fire *downwards*, instead of upwards, as in the common furnace. The fresh coal is thrown on top of the fire as usual, but the smoke is compelled to pass downwards into the fire, and is thus consumed. A furnace of this kind is illustrated and described further on.

FUEL.

1518. In **selecting a fuel** for any particular service, the characteristics of each variety should be well considered. The value of a fuel depends primarily upon the amount of heat which it will give off during combustion, but this is modified by the amount of labor and care required in its use.

The following points should be carefully studied:

1. The amount of labor required for feeding and cleaning the fires.
2. The amount of ashes produced and the labor or cost of removing them.
3. The labor required in cleaning out the soot and dust from the boiler and its settings.
4. The liability to produce smoke, and the cost of the necessary arrangements to prevent it.
5. The extent and cost of the storage required for the fuel and for the ashes.
6. The cost of the fuel delivered upon the premises.

1519. If the ash is easily fusible it will melt and run together, forming large blocks of **clinker.** This will add greatly to the labor required to keep the fire in good order.

All grades of prepared coal, either anthracite or bituminous, should consist of pieces of uniform size, as nearly as practicable.

1520. The practice of burning a **mixed fuel,** that is, a mixture of coarse and fine coal, is a wasteful one. The small pieces burn to ashes before the large lumps are completely consumed. The fire is thus obstructed, with the result that the temperature falls, and the combustion of the large lumps ceases, leaving in each one a central core of unburned coal. When the fire is cleaned, these unburned parts usually go along with the ashes to the ash heap. The loss of fuel from this source is much greater than is generally suspected.

The ashes should be periodically inspected for the purpose of detecting any waste caused by incomplete burning of the coal; and if any such waste is found, the mode of firing should be modified in such a manner as to prevent it. This, of course, applies particularly to large heating boilers or power boilers where a man is in charge.

The heat contained in the gases which pass up the chimney is nearly all wasted. Only a small percentage of it is utilized in moving the gases, by creating a draft. It is, therefore, desirable that the temperature of the escaping gases should be kept as low as practicable.

In the case of a steam boiler, hot-water heater, or hot-air furnace, the temperature in the chimney should not exceed that of the steam, water, or air by more than 100°. Ordinarily this matter is overlooked and the difference is allowed to become very great—as much as 300° to 800° or more—thus causing a great waste of fuel.

Slow combustion is likely to be very imperfect, and is, therefore, wasteful. A moderately high rate of combustion is always to be preferred. In many cases natural draft is insufficient to maintain an economical rate of combustion, and, as a general rule, **forced blast** is preferable. When a forced blast is used, the chimney is relieved of the work of creating a draft, and it becomes merely a discharge pipe for the products of combustion.

1521. Storage of Fuel.—Coal of all kinds should be carefully protected from the weather. When it is exposed to alternate wet and dry, it is slowly oxidized, and the damage is proportional to the richness of the coal in volatile matters. Even hard anthracite suffers considerable damage by exposure.

The space required for the storage of fuel, in cubic feet for each thousand pounds of material, is about as follows:

TABLE 59.

Anthracite coal, prepared "stove" size	18 cubic feet.
Bituminous coal, prepared "stove" size	20 cubic feet.
Coke	34 cubic feet.
Cord wood	38 cubic feet.
Petroleum, in barrels	18 cubic feet.

GRATES.

1522. The purpose of a grate is to support the fuel while burning, and in such a manner that a sufficient supply of air may readily pass through it.

The size of the **air spaces** between the grate bars depends upon the character of the fuel to be burned. For anthracite coal the air spaces should be ⅜ to ½ inch wide, while for coal that cakes much the spaces should be ⅝ to ¾ inch wide.

Ordinary grates are made of cast iron, and when heated they expand unequally. If they are cast in one piece they will crack at the corners, and will soon break up. It is, therefore, best to make them in small sections of one or two bars each, as shown in Fig. 580.

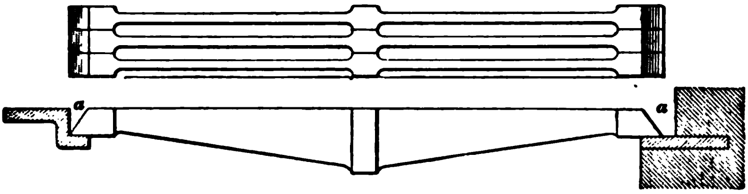


FIG. 580.

If cast-iron bars are exposed to intense heat for a long time, the metal swells and expands permanently. Therefore, plenty of space on all sides of the grate must be provided for expansion. The ends of the bars should be beveled, as shown, so that the dirt at the point *a* will not be caught and compressed between the wall and the bar, as it elongates from use.

This variety of bar should not be made more than four feet long, and if greater length is required, it should be made in two sections.

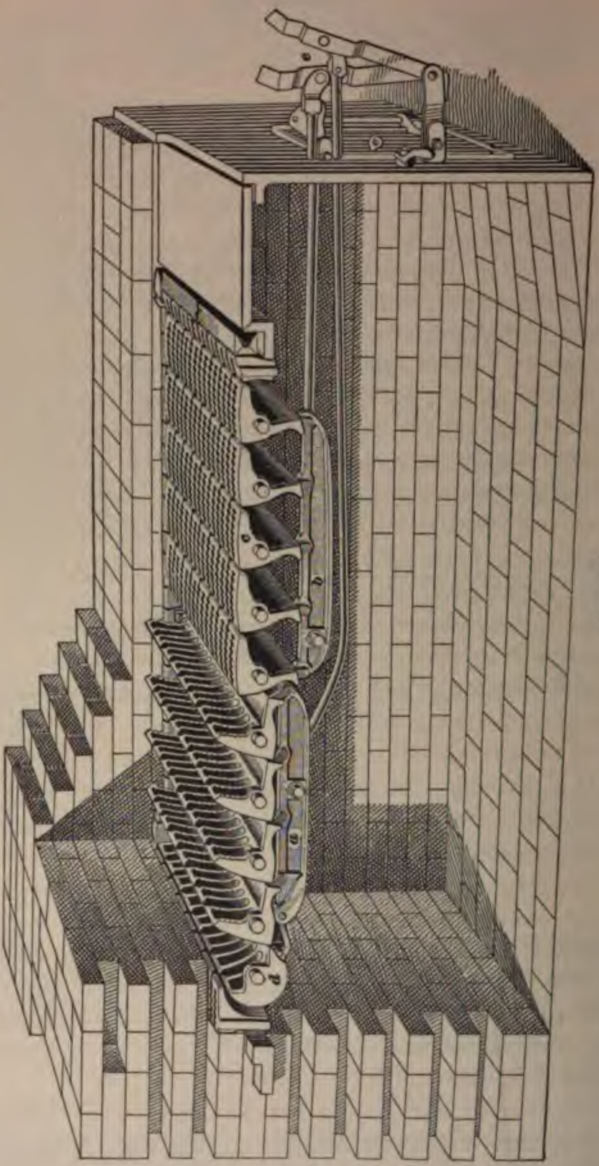


FIG. 581.

1523. If a high rate of combustion is to be maintained, with forced draft, the heat will rapidly destroy the ordinary cast-iron bars. In such cases **water bars** are employed. These consist of wrought-iron tubes through which a plentiful supply of water is made to flow. The water thus warmed is utilized for steam making, etc.

A large variety of grate bars now in use are designed to lessen the labor of cleaning the fire, and also to permit the fires to be cleaned without opening the fire-hole doors.

When a fire requires replenishing, there is usually a layer of ashes several inches in thickness between the grate and the layer of burning fuel. If the grate bars are merely moved to and fro, or are vibrated moderately up and down, the layer of ashes will be more or less broken up and rattled through; but if the ashes are fusible and disposed to cake, the motion given to the shaking grate will fail to remove them.

1524. A superior variety of **shaking grate** is shown in Fig. 581. The bars are hung on trunnions at each end and are connected together by bars *a* and *b*. Ordinarily, they stand as shown at *c* in the right-hand half of the figure, and when it is desired to merely shake the fire and remove the bottom layer of ashes, the points *c* are vibrated from the level shown to the lowest position the connections will permit. The points follow the back of the bar immediately in front of them; thus no unusual opening is made through which the fine fuel might run to waste. The end bar *d* is curved to fit the frame, as shown. When the ashes have accumulated to a considerable thickness, or when they have agglomerated into a mass of cinder or clinker, the points *c* are thrown upwards, as shown in the left-hand half of the figure, thus forming a series of deep pockets. These pockets are closed at the bottom by the main rib, or back plate, of the bars. The fire settles down and forces the ashes into the pockets, thus breaking the caked mass into fragments. When the points are thrown forwards and down to the normal position, the refuse is cut off from the under side of the fire and is dropped into the ash pit. The mechanism is operated by means of a handle which is attached to the short levers shown in front near the ash door at *e*. These grates are made in all sizes, from 16″ × 24″ up to any dimensions required.

CHIMNEYS.

1525. The cause of the draft in chimneys and the mode of computing the velocity of hot air in chimneys and flues were explained in Arts. **1430** to **1434.**

The **draft pressure** which should be produced by a chimney of given height may be found by the following

Rule.—*Ascertain the weight of a column of air one foot square and as high as the chimney, at the atmospheric temperature, and deduct from it the weight of an equal volume of the hot chimney gases, at the average temperature prevailing in the chimney; the difference will be the draft pressure in pounds per square foot of area.*

This may be converted into inches of water by multiplying the pounds per square foot by .193, or dividing by 5.2.

Example.—What draft pressure will be given by a chimney 120 feet high, the temperature of the atmosphere being 60°, of the hot gases 450°, the area of the grates being 40 sq. ft., and the coal being burned at the rate of 10 lb. per sq. ft. per hour?

Solution.—The weight of a column of air at 60°, 1 ft. square and 120 ft. high (see Table 55, Art. **1423**) $= 120 \times .0763 = 9.16$ lb.

The rate of combustion (see Table 58, Art. **1513**) shows that about 19 pounds of air will be used for each pound of coal. During the process of combustion this takes up 1 pound of carbon, and the weight becomes 20 pounds. The chimney gases are thus heavier than an equal volume of air at the same temperature. In this case the proportion is 20 to 19, or an excess of about 5¼ per cent. The weight of 120 cubic feet of chimney gases at 60° is, therefore, $9.16 \times 1.0525 = 9.64$ lb., but at a temperature of 450° (or 910°, absolute) the weight is, according to rule, Art. **1425,** diminished to $9.64 \times \frac{60 + 460}{910} = 5.51$ lb.

The draft pressure will then be $9.16 - 5.51 = 3.65$ lb. per sq. ft., or .704 inch of water. Ans.

1526. Apparently the **area of a chimney** may be found by dividing the volume of the chimney gases in cubic feet per minute by the theoretical velocity due to their temperature. But no reliable rule can be given for this purpose, because a large proportion of the draft pressure is expended in forcing the air through the fire and in overcoming friction, etc., in the flues leading to the chimney. The velocity of the gases in the chimney is thereby reduced to 50, or even 25 per cent. of the theoretical velocity.

It is necessary, therefore, to depend for information upon the data secured by tests and actual service.

1527. The rate of combustion of anthracite coal, per square foot of grate per hour, which may be attained in practice with various heights of chimneys, is shown in the following table. The area of the chimney required per pound of coal thus burned is also given for each height. This is based upon the proportion of 1 square foot of chimney area to 8 square feet of grate surface:

TABLE 60.

SIZE OF CHIMNEYS.

Height of Chimney, Ft.	Rate of Combustion. Coal per Sq. Ft. Grate, per Hour, Lb.	Area of Chimney per Lb. of Coal Burned per Hour, Sq. Ft.
40	11.6	.0108
50	13.1	.0095
60	14.4	.0087
70	15.7	.0080
80	16.8	.0074
90	17.9	.0070
100	19.0	.0067
110	19.9	.0064
120	20.8	.0061
130	21.7	.0059
140	22.5	.0057
150	23.4	.0055

The high rates of combustion here indicated can not be attained unless the connecting flues are very short and straight.

1528. The **construction of a chimney** is a matter of great importance, both as affects the efficiency of a boiler and the safety of a building from fire.

In order to safely withstand the wind, the width of the base of a brick chimney, which stands alone, should always be equal to one-tenth of the height. Iron stacks should be made with a wide base plate well braced to the stack; this base plate should be secured by bolts to a heavy foundation, or else be supported by guy rods.

All brick chimneys, large or small, should be made smooth on the inside, by plastering or by the use of smooth linings. The flue should be of equal dimensions from bottom to top. A round flue is better than a square one, and either of them is better than a narrow rectangular one, because of the smaller resistance from friction.

Where natural draft is employed, the flue, or smoke pipe, through which the gases pass from the furnaces to the chimney should have an area equal to, or a little larger than, the area of the chimney. Abrupt turns in the flue, or contractions of its area, should be carefully avoided, as they greatly retard the flow of the gases. Where one chimney serves several boilers, the branch flue from each furnace to the main flue must be somewhat larger than its proportionate part of the area of the main flue.

The size of a chimney should be adapted to the *maximum* amount of work that it may ever be called upon to do. Chimneys for domestic heating apparatus, etc., which are built into the walls of a house, should be made of generous dimensions, so as to avoid all possible overheating, and the consequent danger from fire.

HEATING AND HEATING APPARATUS.

HEATING AIR.

1529. It is commonly supposed that air can be readily warmed by means of radiant heat. This view is based upon the apparent effects of the rays of the sun in warming the atmosphere. The belief, however, is a fallacy.

It is a well-established fact that radiant heat produces no perceptible effect upon air which is pure and dry. But it is intercepted and readily absorbed by dust and the vapor of water, and since these substances are always present in the atmosphere in greater or less quantities, they operate to absorb heat from the sun's rays, and to impart heat, by conduction, to the air with which they are intermingled. The atmosphere is also warmed by contact with the earth. At a height of three miles or more, the air is nearly free from moisture and dust, and is intensely cold at all times. The highest part of the atmosphere which is warm enough to live in comfortably is that within a mile or so of the earth's surface.

Air can be heated only by *conduction;* that is, by direct contact with hot surfaces or substances. The prime requisite of an apparatus for heating air is an abundance of hot surfaces over which the air may travel.

Heating surfaces, when in operation, are covered with a thin layer, or film, of hot air, and this film clings to the metal with considerable pertinacity. All of the heat which is imparted to the cooler air outside must be transmitted through this film by conduction. If the air is not in perceptible motion, the film will be quite thick and the transmission of heat will be slow; but if the air be moved in a current over the hot surface, the film of *dead air* will be reduced in thickness and will be partially swept away, and the rate of heat transmission will be increased accordingly.

It is evident, therefore, that where air is to be heated, circulation of it is very necessary.

1530. There are two methods of securing the desired circulation: the **natural-draft** system, which operates wholly by convection, and the **forced-draft** system, in which the air is propelled by fans or blowers.

If the air is moved by mechanical means, any desired velocity may be given to it. By using a high velocity, the heating surfaces may be continually swept clean of adherent hot air, thus enabling the transmission of heat to be made with maximum rapidity.

The currents which are induced by convection move at very moderate velocities; consequently, the heating surfaces can not be operated so to give the same degree of efficiency as with the forced-draft system.

1531. The **transmission of heat** from a radiator or similar heating device to the air which surrounds it depends mainly upon the difference in temperature between the hot gas or fluid within it and the air to be heated, and also upon the velocity given to the film of air which is in close contact with the heating surfaces.

It is affected, in a small degree, by the *form* of the heating surfaces and also by their *condition*, whether smooth or rough.

Neither the kind of metal employed nor its thickness (within the range usually employed for such purposes) seems to make much difference.

The number of heat units transmitted per hour through one square foot of emitting surface, for each degree of difference in temperature between the fluids upon the opposite sides of the heating surface, is called the **coefficient of transmission** of that heating surface.

The conditions which impede the emission of heat by *radiation* have a much smaller effect upon the transmission of heat by *conduction*. The proportion of heat emitted by radiation in radiators employed for direct heating is seldom more than 30 or 40 per cent. of the total emission; and it is practically nothing in indirect heating.

As air is not heated appreciably by radiant heat, the use of the word *radiator* to indicate a steam heater, etc., is clearly wrong; but the usage is so firmly established that the error can not very well be corrected.

1532. In experimenting with the *condition of heating surfaces* it is found that, with surfaces of various kinds, the rate of emission of heat is about as follows, the total emission from a new cast-iron plate having its natural surface (as cast) being taken as 100:

Cast iron, new	100
Cast iron, rusty	102
Wrought iron, ordinary or "black"	93
Wrought iron, bright, but not polished	72
Surface covered with lampblack, dull	106
Surface covered with white lead powder, dull	106

It is found, also, that the rate of emission is affected by painting or bronzing about as follows, the amount given off without paint being taken as 100:

Two coats of asphaltum paint	106
Two coats of white lead paint, dull	109
Rough bronzing	106
One coat of glossy white paint	90

This last item shows the effect of a glossy, or polished, surface in reducing the emission of heat.

1533. In **heating fluids** of various kinds, it is found by experiment that the amount of heat transmitted within a given time depends less upon the kind of metal used in the radiator than upon the nature of the fluids which are brought into contact with it.

Steam or hot water will impart heat to a metal plate upon one side much faster than air will absorb it from the opposite side; consequently, there may be a considerable difference in extent between the interior and exterior surfaces of a radiator tube which is employed for heating air, without any perceptible loss of efficiency.

But if the radiator is used to heat water, the inner and outer surfaces should be as nearly equal as possible, because water will absorb heat from the metal upon one side as rapidly as the steam will impart it on the opposite side. The metal, then, should be made as thin as is consistent with strength and durability.

If hot gas is used to heat air, as in hot-air furnaces, the heat-absorbing and emitting surfaces should be of equal extent.

FORM OF HEATING SURFACES.

1534. Heating surfaces which have no projections of any kind are classified as **plain surfaces,** while those having ribs, knobs, pins, or other projecting parts, are called **extended surfaces.**

The object sought in the construction of extended surfaces is to make the area of the emitting surface greater than that of the absorbing surface. By this means heat may be transferred from a fluid which gives it off readily to one which takes it up slowly with but little decrease in temperature of the heat-transmitting surfaces.

A plate having extended surfaces will emit more heat per hour than the same plate without the extensions, but less than a plain plate having the same actual area of exposed surface.

Thus, in Fig. 582 the internal surfaces marked *c* and *d* are of equal area, but the heat which passes through *c* is emitted from the whole exposed surface of the rib, or lug, while that which passes through *d* is emitted from a smaller surface. The emission through *c* will, therefore, be larger than that through *d*.

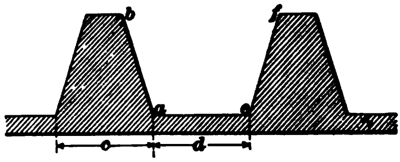


FIG. 582.

This advantage is partially neutralized, however, by the lodgment of hot air in the spaces between the projections. The radiator becomes enveloped in a layer of hot air, which does not move away by convection. This greatly impedes the transmission of heat to the current of air which passes over the outer ends of the projections. The air will be warmer at the surface *a e* than at the points *b*, *f*.

Extended surfaces have no advantage over plain surfaces unless the velocity of the air passing over them is sufficient to sweep them clean of hot air as rapidly as it is formed. When air is moved wholly by convection, as is the case when a radiator stands in still air, the plain surfaces clear themselves of hot air better than the extended surfaces do, and they are, therefore, more effective.

In making comparisons between plain and extended surfaces, the area of the latter should be computed as though the projections were absent. It is a tedious and difficult task to compute the actual exposed area of extended surfaces, and such estimates are always liable to considerable inaccuracy.

It is the custom of manufacturers, however, to rate extended surfaces by their actual exposed area. This practice is very misleading (especially to persons who are not aware of the lower efficiency of such surfaces) when used in still air or in currents of low velocity.

1535. The efficiency of a heater or radiator will increase as the velocity of air passing over it is increased, but not in the same proportion. With increased velocity, the duration of contact of air with the hot surface is shortened, and the rise of temperature will be less, but the quantity of air heated will be increased so much that the total heat given off from the radiator, per square foot of surface per hour, will be increased.

The coefficient of heat transmission increases approximately as the square root of the velocity of the air. Thus, if each square foot of surface emits 4 B. T. U. per hour for each degree of difference in temperature of the steam and the cold air when the air moves 250 feet per minute, the rate of emission when the velocity of the air is raised to 500 feet per minute will be increased to 5.66 B. T. U., as follows:

$$\sqrt{250} : \sqrt{500} :: 4 : x = 5.66 \text{ B. T. U.}$$

ARRANGEMENT OF HEATING SURFACES.

1536. The efficiency of a radiator will depend to a considerable extent upon the direction in which the air is moved over the heating surfaces. Fig. 583 shows a vertical tube standing in still air. The tube is heated by steam, and its surface has a temperature which is practically uniform throughout. The air, which is warmed at the lower end of the tube, flows upwards and envelopes the upper part in a current of hot air. The emission of heat will be slower from the upper part of the tube than from the lower part, because the difference in temperature between the air and metal is less.

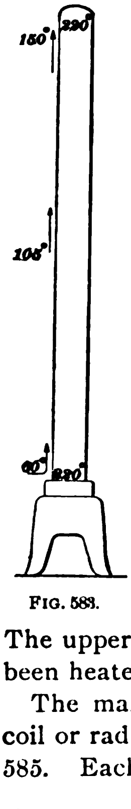


FIG. 583.

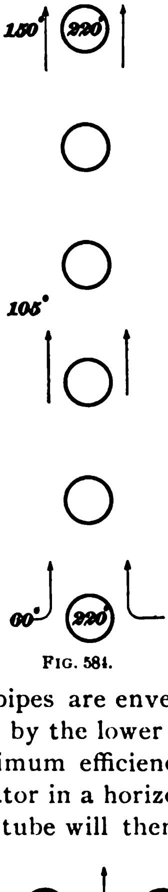


FIG. 584.

The temperature at the various points is marked on the sketch.

A similar loss of efficiency occurs in a common coil of horizontal pipes laid vertically over one another, as shown in Fig. 584. The upper pipes are enveloped in the warm air which has been heated by the lower pipes.

The maximum efficiency can be attained by placing the coil or radiator in a horizontal position, as indicated in Fig. 585. Each tube will then operate upon air of equally low temperature, and, consequently, the rate of emission will be greater than in the cases shown in Figs. 583 and 584.

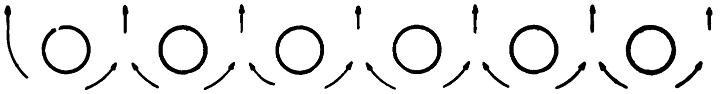


FIG. 585.

If radiator tubes are grouped together in large numbers, as in Fig. 586, the efficiency of the tubes in the interior of the group will be much less than that of the outside tubes, because the access of cold air to them is practically cut off, and they can act only upon air which has been already warmed by the outer tubes.

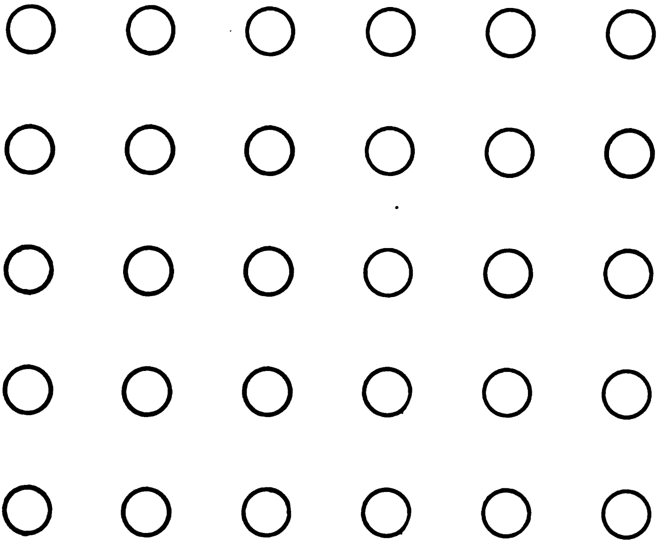


FIG. 586.

Their efficiency is still further reduced by the fact that nearly all of the heat which they emit by radiation is intercepted and cut off by the outer tubes.

Therefore, the most effective form of radiator or coil for direct heating is one having only a single row of tubes.

If the inner tubes of a group can in some way be plentifully supplied with cold air, they will be as useful as the outer tubes. When forced circulation is employed, there is little difficulty in driving the cold air over the whole of the tubes; but with natural draft only, it is necessary to modify the shape and arrangement of the tubes to secure a satisfactory result.

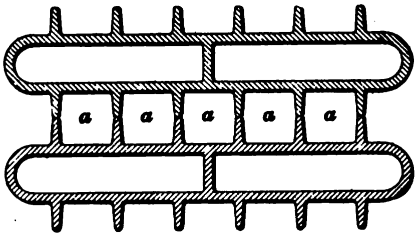


FIG. 587.

1537. Figs. 587 and 588 show varieties of radiator tubes which are so shaped that, when they are assembled in a group, they enclose vertical air flues as shown at *a*. The bases of the tubes are set high enough above the floor to permit an abundant flow of air into the flues at the bottom. Radiators constructed in this manner are called **flue radiators.**

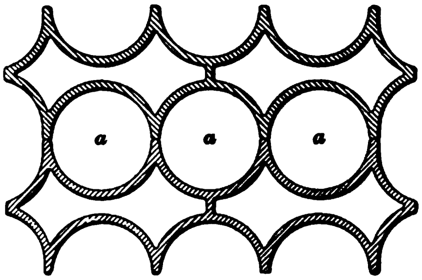


FIG. 588

The advantages of this construction are that the interior parts of the radiator are fairly well supplied with air, and that the flues impart a higher velocity to the air than it would otherwise obtain. The emissive capacity of the two forms shown in Figs. 587 and 588 will differ greatly because of the relative amount of plain and extended heated surfaces which they afford, and also on account of the proportion of heating surface to the area of the flues.

INTERNAL CIRCULATION.

1538. Hot water circulates solely by convection. Those portions which lose some of their heat become heavier by contraction, and gravitate to the lower part of the radiator. Therefore, the supply should be introduced near the top, and the return pipe should be connected at the bottom.

Convection occurs in a much more forcible manner in a body of steam which is exposed to cooling influences. The portions of steam which lose their heat become condensed into water, and this is so heavy that it readily flows away by gravity. The flow of steam towards the point of cooling is enormously increased by the change in volume which occurs in condensation. When a cubic foot of steam condenses, the resulting water occupies about one cubic inch only, and the remainder of the space which it formerly occupied must be filled with fresh steam. Thus, a strong flow will be kept up as long as condensation continues.

It is practicable to operate a steam radiator with a single pipe connection which admits the steam and also serves for the escape of the condensed water. The water, however, must flow in a direction contrary to that of the steam, and the two currents, therefore, interfere to an extent which is sometimes troublesome.

In the case of hot water, the force of natural circulation is very small, and the application of power to drive the water forwards is highly beneficial. The water can then be kept at a maximum temperature throughout the whole system, and can be forced to any point desired.

CONSTRUCTION OF RADIATORS.

1539. Radiators which are made of ordinary steam pipes and fittings, as shown in Figs. 589 and 590, are usually called **coils.** Coils are also made of continuous pipes, bent and curved to a great variety of shapes; such coils are generally used for manufacturing purposes.

1540. The **continuous flat coil,** Fig. 589, is made of straight pipe connected by return bends. The circulation of the fluid through it is direct and certain, and it is regarded as the most efficient form of radiator in common use.

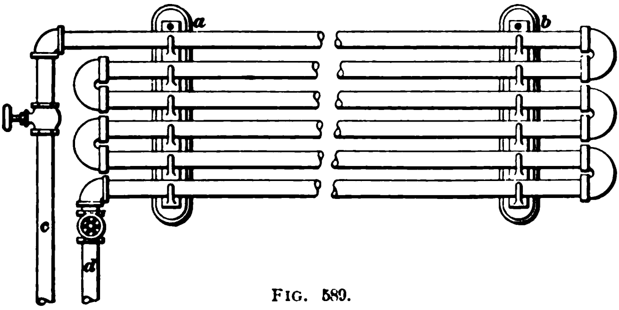


FIG. 589.

1541. A **miter coil** is shown in Fig. 590, the pipes being connected between two manifolds *a* and *b*. The steam moves forward simultaneously through all the pipes; therefore its velocity will be one-sixth of the rate in a single pipe, as in Fig. 589. The circulation is likely to be uneven, because the fluid entering at *g* will naturally, owing to its momentum, flow to the end of the manifold, and so a greater quantity will enter the pipe *c* than pipe *f*. The path through *c c* is shorter than through *f d*, and, the friction being less, the main part of the current will go that way.

It will be noted that all the horizontal pipes are connected to the manifold *a* by means of elbows and vertical pipes. This must always be done, so as to permit the several pipes to expand independently, as their varying temperatures may require. The vertical pipes will bend or yield sufficiently to accommodate the difference in expansion.

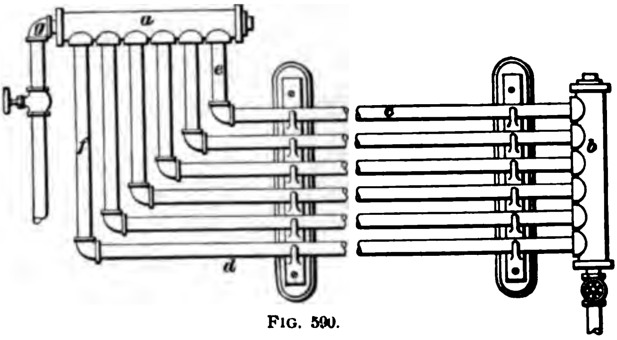


FIG. 590.

1542. If a coil is made by connecting two manifolds, as in Fig. 591, it will be difficult to keep it steam-tight. The upper pipes will expand more than the lower ones, and they will either bulge and spring, as shown, or will crack or break some of the connections.

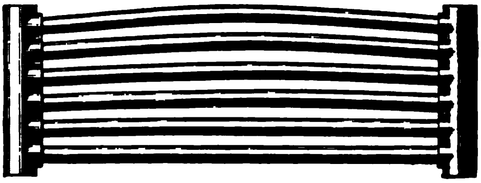


FIG. 591.

1543. When several flat coils are grouped together, as shown in Fig. 592, the construction is called a **box coil.**

The spring pieces of a coil should be put together with right and left screw joints, so that the coil may be readily disconnected at any time and without unnecessary labor.

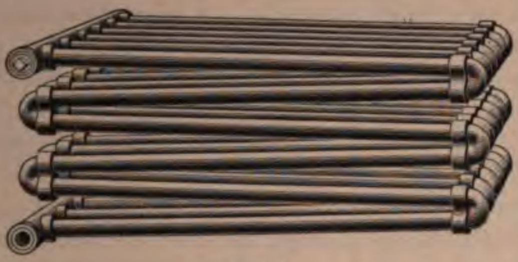


FIG. 592.

The size of pipe used for constructing coils depends chiefly upon the pressure of steam to be employed, the length of the coil, and the force of the circulation through it. A coil like Fig. 590 could be made of smaller pipe than one like Fig. 589, because the current of heating fluid is diffused throughout the whole series instead of passing entire through each pipe. The difference, however, would seldom exceed one or two sizes of pipe.

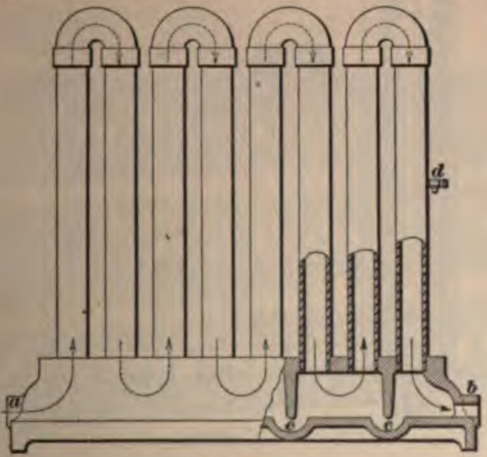


FIG. 593.

Pipe coils must be arranged so that all of the water which is condensed within them may flow easily towards their outlets.

1544. Fig. 593 shows an old **positive circulating radiator,** still in use, which has wrought-iron pipes attached to a cast-iron base. Under the middle of each loop there is a partition which partially divides the base into sections. The edges of the partitions dip into water pockets *e*, *e*, and when these are filled with water, the steam (which enters at *a*) is compelled to flow up and down through each loop, as though the loops formed a continuous coil. The water, however, is free to make its way directly to the outlet *b*. *d* is an air vent.

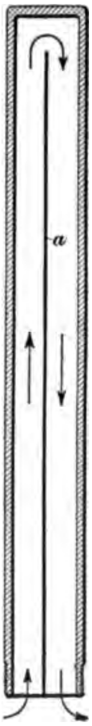


FIG. 594.

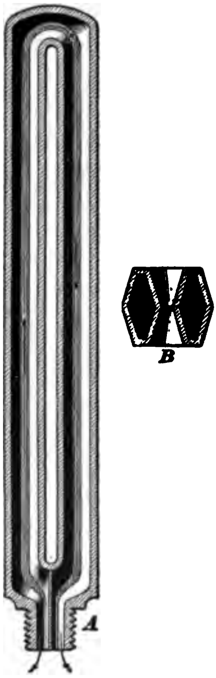


FIG. 595.

1545. Fig. 594 shows a tube called the **Nason tube.** It is connected to the radiator base by a single screw joint, and is divided into two passages by means of a sheet-iron plate *a* which extends nearly to the top of the tube, as shown. The steam rises on one side, passes over the end of the plate, and descends on the opposite side of the tube. Each tube thus forms a complete *loop*, or circuit.

1546. Fig. 595 shows the **Bundy loop,** in longitudinal section at *A* and cross-section at *B*. This, also, is screwed into a cast-iron radiator base of suitable shape, and the steam moves up one branch of the tube and down the other.

1547. The **Detroit loop** is shown in Fig. 596. Each loop is complete in itself, and requires no base or supply chamber. The loops are connected together, in any number desired, by means of nipples *a* and *c*. When the connection at the top is not desired, the loops are bound together by a bolt which passes through the space between them, shown in the end view.

The construction of this class of loops is often varied so that they comprise three or even four parallel tubes. They are also modified so as to form flue radiators.

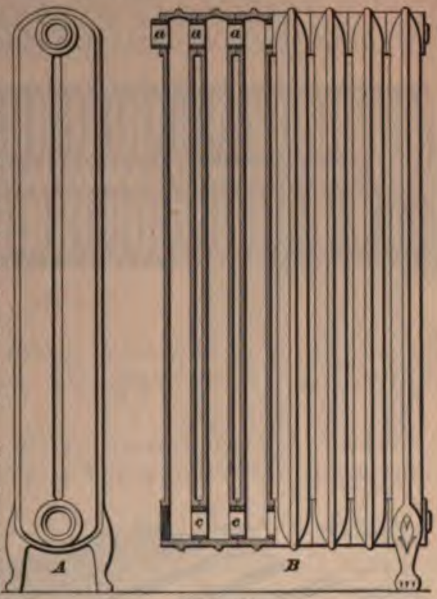


FIG. 596.

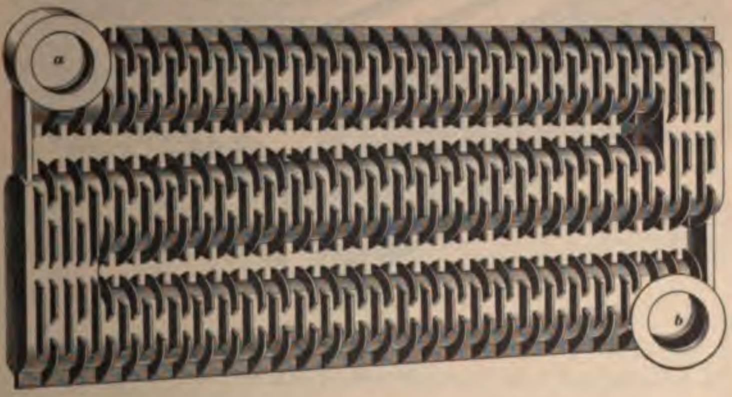


FIG. 597.

1548. Figs. 597 and 598 show **extended surface loops** which are especially designed for indirect heating.

The form shown in Fig. 597 has two connections at *a* and *b*, and is suitable for either hot water or steam, while the other has a single connection, and is suited for steam only.

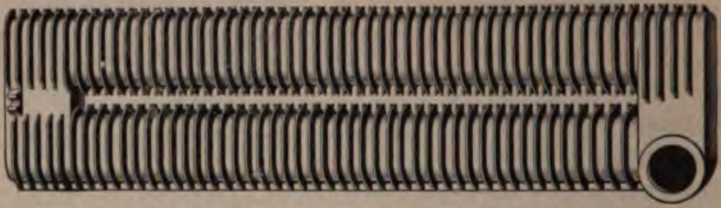


FIG. 598.

These loops, or *sections*, are coupled together by nipples, as illustrated at *a* and *c* in Fig. 596.

1549. Another variety which is in extensive use for indirect heating is shown in Fig. 599. This is called a **pin radiator,** because the extensions of the heating surface are made in the shape of small conical pins. The sections may be coupled at both top and bottom, as shown.

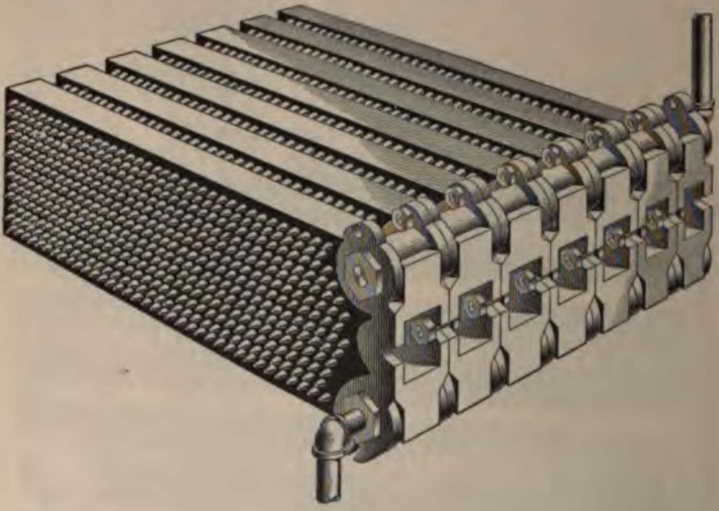


FIG. 599.

1550. Fig. 600 shows a cross-section *A* and sectional side view *B* of a radiator composed of **three-column sections.** It is peculiarly adapted to the use of hot water. Both the supply and return pipes are connected at the bottom. Each loop consists of three tubes; a large middle tube *a* up which the hot water ascends, and two smaller side tubes *b*, *b* by which the cooled water descends to the return pipe *e*. The loops are connected at the top and bottom by nipples *c*, *c* of large diameter which provide an ample waterway.

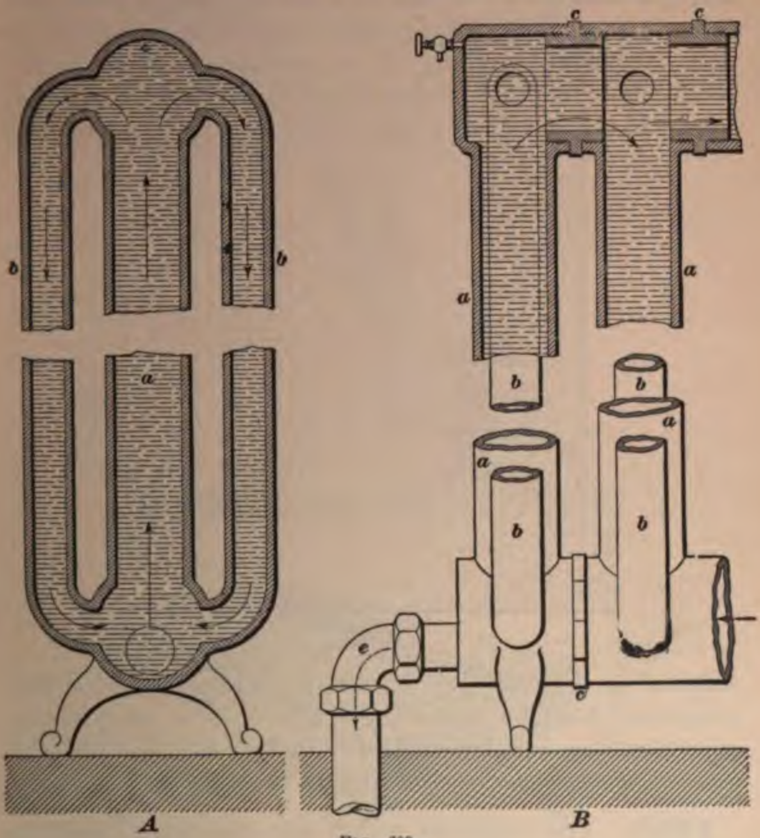


FIG. 600.

1551. Cast-iron radiators of the kind shown in Fig. 596 should have supports at short distances apart. If the radiator is more than thirty-six inches long, the middle loop should be provided with feet, and in the case of very long and low radiators, the supports should not be more than thirty inches apart. Every foot should bear firmly on the floor, to prevent sagging of the radiator and consequent straining or rupture of the joints, or cracking of the castings. If the feet do not rest solidly on the floor when the radiator is set up, they should be leveled up with thin wedges or blocks. Sometimes radiator feet are provided with **leveling screws,** as shown in Fig. 601; *c* is the foot, and *a* the leveling screw bearing on the plate *b*.

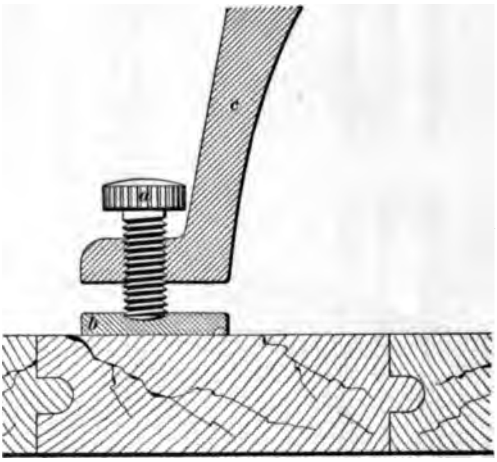
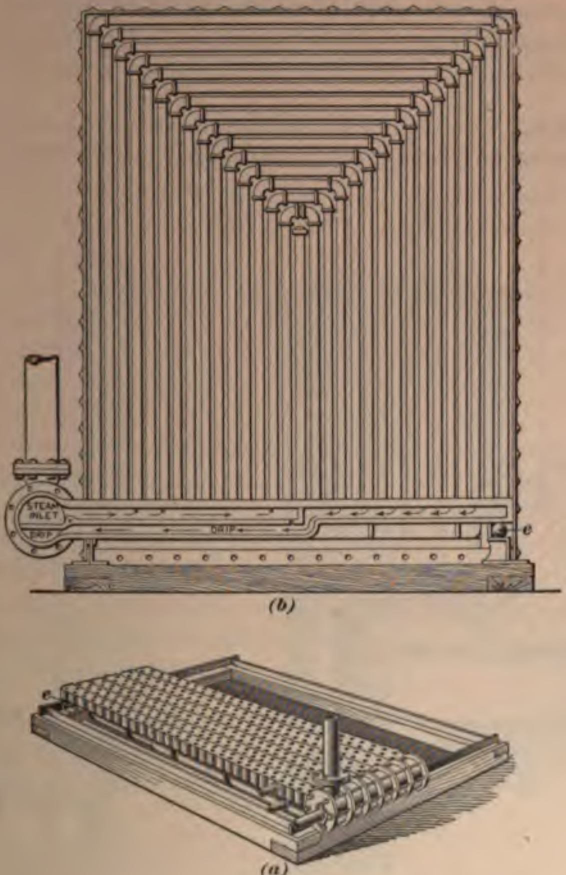


FIG. 601.

1552. The radiators which are commonly used for heating air on a large scale, where forced draft is employed, are usually constructed as shown in Fig. 602; (*b*) is an elevation and (*a*) a plan. The tubes are of 1-inch steel or wrought-iron pipe, and are connected at the top by cross-pipes instead of return bends, thus preventing all distortion by unequal expansion.

The tubes are *staggered*, so that those in one row stand opposite the spaces between the tubes in the preceding row. By this means, all parts of the air current (which passes through horizontally) are brought into contact with the tubes and thoroughly heated.



(b)

(a)

FIG. 602.

The *base sections*, or *headers*, are coupled together at one end by flanged joints. The group of base sections may be divided into two or more parts, each of which may have an independent supply and return pipe. Thus, the whole heater may be used, or only a part of it, as desired. The sides of the sections are corrugated so that they interlock and leave no open spaces between them. The further end of each section rests upon a roller *c*, so that they can expand and contract freely without straining. The course of the steam through the heater is shown by the arrows.

1553. The ordinary varieties of vertical tube radiators may easily be adapted to **direct-indirect** heating (see Art. **1573**). The mode of applying a direct radiator of the Nason or Bundy type to that purpose is shown in Fig. 603. The base of the radiator is enclosed by plates *a*, so that the fresh air, which comes in through the tube *b*, is compelled to pass upwards and between the hot tubes before it can escape into the room.

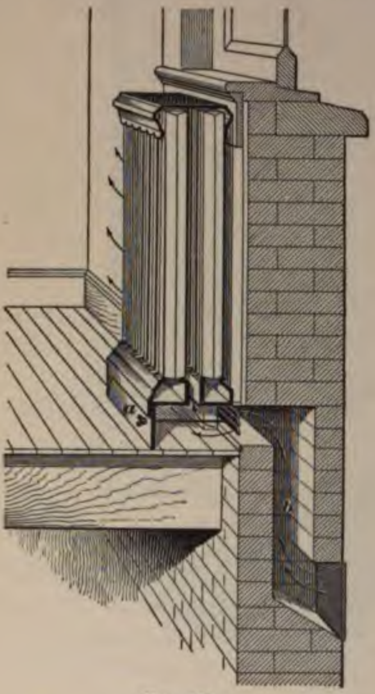


FIG. 603.

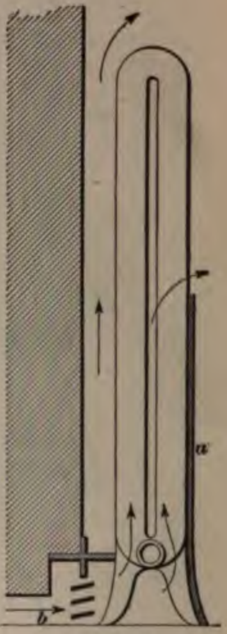


FIG. 604.

Fig. 604 shows a Detroit loop radiator which is enclosed by a plate *a* to one-third or more of its height. The entering air (at *b*) is thus compelled to flow over the radiator surfaces and become properly warmed.

Flue radiators may be applied in a similar manner by enclosing the base and compelling the fresh air to pass up the flues.

EMISSIVE CAPACITY OF RADIATORS.

1554. The following general conclusions are deduced from the results of extensive experiments and tests of radiators:

The various materials used for radiators do not show any considerable difference in emissive capacity under similar conditions of internal and external temperature.

The rate of emission is practically the same for hot water or steam, for equal differences in temperature.

The rate of emission is not affected by the internal volume of the radiator tubes, provided the sectional area is large enough to afford good internal circulation.

In still air, radiators having but one row of tubes are more effective than those having two or more rows.

With equal surfaces, in still air, low radiators are more effective than tall ones, and horizontal tubes are more effective than vertical ones.

1555. The following table shows the actual emissive capacity of several varieties of *direct radiators* working in still air, as determined by experiment:

TABLE 61.

RADIATORS—VERTICAL TUBE, PRIME SURFACE.

Total emission of heat per hour, from direct radiators, in still air per square foot of external surface, for each degree difference of temperature.

Difference in Temperature, F°.	Vertical Tubes, Massed.		Vertical Tubes, Single Row.	
	40 Inches High, B. T. U.	24 Inches High, B. T. U.	40 Inches High, B. T. U.	12 Inches High, B. T. U.
50	1.29	1.54	1.46	2.01
60	1.33	1.58	1.50	2.06
70	1.36	1.62	1.54	2.12
80	1.39	1.66	1.58	2.17
90	1.41	1.70	1.62	2.22
100	1.46	1.74	1.65	2.27
110	1.49	1.78	1.69	2.32
120	1.52	1.82	1.73	2.38
130	1.56	1.86	1.77	2.43
140	1.59	1.90	1.81	2.48
150	1.63	1.94	1.85	2.53
160	1.66	1.98	1.88	2.59
170	1.69	2.02	1.92	2.64
180	1.73	2.06	1.96	2.70
190	1.76	2.10	2.00	2.75
200	1.80	2.14	2.03	2.80
210	1.83	2.18	2.07	2.85
220	1.86	2.22	2.11	2.90
230	1.90	2.27	2.15	2.96
240	1.93	2.31	2.19	3.01
250	1.97	2.35	2.23	3.06

1556. The **comparative efficiency** of flue radiators and plain surface radiators of the same size may be seen in the following table of experimental results. The data in columns A, C, E refer to the radiators in their original condition, having the usual ribs, etc., as shown in Fig. 587, while those in columns B, D, F refer to the same radiators having all ribs and "extensions" removed.

TABLE 62.

FLUE RADIATORS—NATURAL DRAFT.

1557. Heat emitted per square foot of actual surface per hour, for each degree difference in temperature.

Surfaces.		Heat Emitted per Sq. Ft. per Hour, per Degree Difference.		Total Heat Emitted per Hour, per Degree Difference.	
Extended, Sq. Ft.	Plain, Sq. Ft.	Extended, B. T. U.	Plain, B. T. U.	Extended, B. T. U.	Plain, B. T. U.
A	B	C	D	E	F
57.80	40.40	1.65	1.97	95.37	79.58
6.40	4.24	2.05	2.39	13.12	10.13
63.10	41.20	1.39	1.85	87.81	76.22
7.18	4.50	1.90	2.24	13.64	10.08

It will be observed that while the rate of emission from the plain surfaces is higher than that from the extended surfaces, yet the total emission is less. This result is due to the great difference in area of the actual emitting surfaces.

1558. The average rate of emission of heat from ordinary *indirect radiators* which are enclosed in a box and deliver warm air to rooms above through a vertical flue is shown in the following tables:

TABLE 63.

INDIRECT RADIATORS—NATURAL DRAFT, EXTENDED SURFACES.

Total emission of heat per sq. ft. of actual surface per hour, for each degree difference in temperature.

Height of Flue, Feet.	Velocity of Air in Feet per Second.	Emission of Heat per Sq. Ft. per Hour, per Degree Difference, B. T. U.
5	2.90	1.70
10	4.10	2.00
15	5.00	2.22
20	5.70	2.38
25	6.30	2.52
30	6.70	2.60
35	7.14	2.67
40	7.50	2.72
45	7.90	2.76
50	8.20	2.80

TABLE 64.

INDIRECT RADIATORS, PLAIN SURFACES, FORCED DRAFT.

Total emission of heat per sq. ft. of surface per hour, for each degree difference in temperature.

Velocity of Air, Feet per Second.	Heat Emitted, B. T. U.	Velocity of Air, Feet per Second.	Heat Emitted, B. T. U.
3	3.42	12	6.93
4	4.00	14	7.50
5	4.50	16	8.06
6	4.94	18	8.50
7	5.33	20	9.00
8	5.71	22	9.42
10	6.33	24	9.79

The rate of emission of heat from radiators of the general style shown in Fig. 602, which are specially designed for use with *forced blast* and are composed mainly of steel or wrought-iron pipe, is shown in Table 64.

AMOUNT OF RADIATOR SURFACE REQUIRED.

1559. The method of computing the amount of radiator surface required for any given service is as follows:

Having ascertained the amount of heat to be supplied, in heat units per hour, we next find the difference in temperature between the air to be heated and the heating fluid which is to be used in the radiators.

If hot water is used, the temperature considered should be the average of its temperatures at entering and leaving the radiator.

The coefficient of emission may then be found by referring to the preceding tables. The coefficient or number which corresponds to the given difference of temperature and to the kind of radiator which most nearly resembles the variety to be used should be multiplied by the difference in temperature in degrees. The product will be the total emission of heat per square foot per hour which may be expected.

The area of radiator surface required may then be found by dividing the total amount of heat required per hour by the emission from one square foot as computed.

EXAMPLE.—A certain building requires a supply of heat amounting to 200,000 heat units per hour, and it is to be heated by steam having a temperature of 220°. The radiators are to be of the Detroit loop variety, 40 inches high, and are to heat by the direct system. How many square feet of radiator surface will be required to maintain the air in the building at 70°?

SOLUTION.—The difference in temperature between the heating agent and the air will be 220° − 70° = 150°. The coefficient of emission for that difference of temperature is given in Table 61 as 1.63 for massed surfaces and 1.85 for a single row of tubes, 40 inches high. The efficiency of the radiator named will be intermediate of these, and the coefficient may be taken as 1.75. Then, the area of radiator surface required will be

$$\frac{200,000}{150 \times 1.75} = 762 \text{ sq. ft.} \quad \text{Ans.}$$

1560. For indirect heating, a greater amount of heat will be required. Of course, no fresh hot air can be introduced unless an equal amount of air be expelled from the room at the same time. Consequently, all of the heat contained in the fresh air current below 70° (or the desired temperature of the room) will be lost by passing off with the spent air—that is, by ventilation. The fresh air current must be heated from 20° to 50° hotter than the desired temperature of the room, so that, in cooling down to that temperature, it will give off an amount of heat sufficient to make good the loss by conduction through the walls, windows, etc.

Thus, in using a current of fresh air having a temperature of 110°, to maintain a room at 70°, the external temperature being zero, $\frac{70}{110}$ of the heat imparted to the current will be lost by ventilation, and only $\frac{40}{110}$ will be available to compensate for the loss of heat from the room through the windows and walls.

EXAMPLE.—The loss of heat from a certain building, by conduction through the walls and windows, is 200,000 B. T. U. per hour. It is desired to heat the building by the indirect system with natural draft, with steam having a temperature of 220°. The average temperature of the hot air at entering the rooms should be 40° above that in the rooms. The building is two stories high, and all of the radiators should be located in the basement. How many square feet of radiator surface will be required to maintain the internal temperature of the building (neglecting the basement and attic) at a temperature of 70°, the outer air being at zero?

SOLUTION.—The losses of heat are as follows:

By conduction, $\frac{40}{110}$ of the total, or 200,000 B. T. U.
By ventilation, $\frac{70}{110}$ of the total, or 350,000 B. T. U.
The total loss per hour is 550,000 B. T. U.

The height of the flues, we will say, is about 10 feet on the first story, and 20 to 25 feet to the second story; the coefficient of emission from the radiators will be $\frac{2 + 2.5}{2} = 2.25$ B. T. U. per hour. The difference between the steam and the cold outer air is 220°.

Then, $$\frac{550,000}{2.25 \times 220} = 1,111 \text{ sq. ft.} \quad \text{Ans.}$$

1561. One of the most simple, and probably most correct, empirical rules used for computing the size of direct radiators is that originated by Mr. Wm. J. Baldwin and is as follows:

Rule.—"*Divide the difference between the temperature at which the room is to be kept and that of the coldest outside atmosphere by the difference between the temperature of the steam pipes and that at which you wish to keep the room, and the quotient will be the square feet, or fraction thereof, of plate or pipe surface to each square foot of glass, or its equivalent in wall surface.*"

The quantity of heating surface found by this simple rule merely compensates for the amount of heat lost by transmission through the windows, walls, and other cooling surfaces; it does not provide for cold air entering the room through loosely fitting doors, windows, etc., and an ample allowance must be made for this. Some buildings are so poorly constructed that 50 per cent. or more must be added to the amount of heating surface obtained by the above rule, in order to counteract the cooling effect of these air leakages. A common practice is to add 25 per cent. for buildings of ordinarily good construction. Besides this addition for air leakage, an ample allowance should be made for rooms exposed to cold winds, and this allowance should, if possible, be made in the form of an auxiliary radiator to prevent overheating the rooms during moderate weather.

1562. Suppose that we have three rooms *A*, *B* and *C*, as shown in Fig. 605, of precisely the same dimensions, and, consequently, having the same cubical contents, the rooms being each 25 feet long by 20 feet wide, with a 10-foot ceiling.

Let us also suppose that the halls, or corridors, *D* and the other rooms in the building will be warmed to a temperature equal to that desired in *A*, *B*, and *C* by other radiators not shown; first proceed to find, by rule, Art. **1561,** the amount of heating surface required to maintain a temperature of 70° F. in A, B, and C, assuming that the radiators will be heated by steam having a pressure of 5 lb. by the gauge, the outside temperature being 10° below zero. Let us suppose that the windows are each 6 ft. × 3 ft., and that the exposed walls are built of good ordinary brick, lathed and plastered inside.

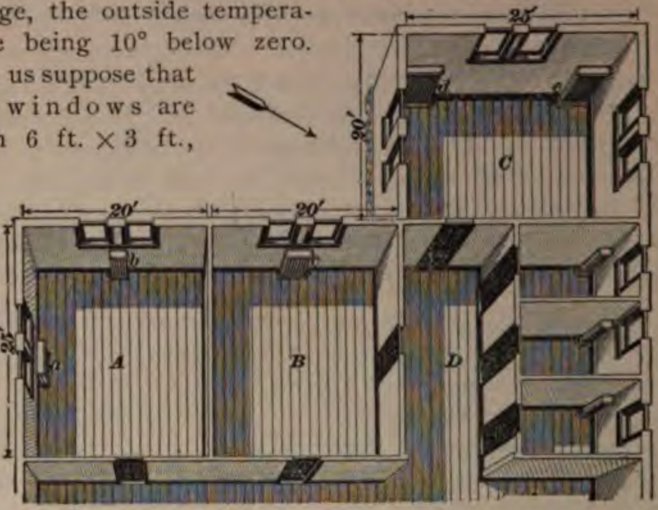


FIG. 605.

Let S = number of square feet of radiating surface required to counteract the cooling effect of the glass and its equivalent in *exposed* wall surface.

t = difference in degrees F. between the desired temperature of the room and that of the external air.

t_1 = difference in degrees F. between the temperature of the heating surface and that of the air in the room.

s = number of square feet of glass and its equivalent in exposed wall surface.

Then, expressing rule, Art. **1561**, as a formula, we get

$$S = \frac{t}{t_1} s.$$

When lathed and plastered brick walls are used, as in the figure, it is safe to estimate that about 10 square feet of wall surface will be equivalent in cooling power to one square foot of glass; consequently, in this case,

$$\frac{\text{wall surface}}{10} = \text{equivalent glass surface.}$$

Let us commence with the room *A*; the amount of glass surface here is $6 \times 3 \times 4 = 72$ sq. ft. To this must be added the exposed wall surface reduced to a glass equivalent; thus,

$$\frac{10\,(25 + 20) - 72}{10} = 37.8 \text{ sq. ft.}$$

Since we assume that the inner walls, floors, and ceilings are not cooling surfaces, the only cooling surfaces we have to calculate against in the case of *A* is 72 sq. ft. + 37.8 sq. ft. = 109.8 sq. ft. $= s$.

1563. The temperature of steam at 5 pounds gauge pressure is 227°, and the difference between 70° above zero and 10° below zero is 70° + 10°; therefore, substituting in the formula, we have,

$$S = \frac{70 + 10}{227 - 70} \times 109.8 = 56 \text{ sq. ft., nearly.}$$

This, however, only counteracts the cooling effect of the walls and windows, and to make reasonable allowance for air leakage, we will add 25% of the above amount, or 14 sq. ft., which gives us $56 + 14 = 70$ sq. ft. of direct radiating surface.

Now, suppose that we allow 20 per cent. of the direct radiating surface (70 sq. ft. in this case) for a moderate exposure to winds; the amount of heating surface, that is, the size of the radiator which we would place in *A*, will then be 70 + 14, or 84 sq. ft.

For convenience, we may divide this into two radiators, *a* having an area of 56 sq. ft. and *b* an area of 28 sq. ft. This will so divide the radiator surface that one-third, or 28 sq. ft., may be used for duty during mild weather; two-thirds, or 56 sq. ft., for moderate cold weather, and the whole, or 84 sq. ft., for use during severe weather.

In like manner and under the same conditions, we find that the sizes of the radiators *c*, *d*, and *e* should be, respectively, 40, 82, and 42 sq. ft.

As the coldest winds blow in the direction of the arrow, we place the 82 sq. ft. radiator in the left-hand exposed corner of the room *C*. A better distribution of the radiator surface in this room would be to make *d* 42 sq. ft. only, and place a radiator having 40 sq. ft. between the windows towards which the arrow points; this will give a more uniform temperature to the room.

1564. The reader will observe that *A*, *B*, and *C*, which are three rooms having the same shape and cubical contents, respectively require 84 sq. ft., 40 sq. ft. and 124 sq. ft. of heating surface, in order to maintain a temperature of 70° F. in each while the outer atmosphere is 10° below zero, and he will observe how imperfect must be the rule-of-thumb method of proportioning radiators to the cubical contents of the several rooms.

For direct-indirect heating, the area of radiator surface required may be found by computing the area required for direct heating, and adding 25 per cent. to that amount.

Thus, in the example given in Art. **1559,** if the heating be done by the direct-indirect method instead of the direct method, the radiator surface required would be $762+190.5 = 952.5$ sq. ft. (For indirect radiation add 50%.)

LOSS OF HEAT FROM BUILDINGS.

1565. Heat escapes from buildings in two ways: first, by conduction through the windows, walls, floor, and roof, and, second, by ventilation or leakage of warm air. The loss from the latter cause will depend upon the tightness of the windows and doors and upon the thoroughness of the construction of the walls, especially in wooden buildings. If the outer walls are exposed to the wind, the loss of heat by conduction will be increased from 10 to 30 per cent., while, if they are not wind-tight, the loss by escape of air will be increased to an unknown amount.

1566. The rate at which heat will be lost through walls and windows has been found, by careful experiment, to be proportional to the amount of the difference in temperature between the inside and outside air. The rate of loss under ordinary conditions, and in rooms which have only a moderate exposure to wind, is shown in the following table:

TABLE 65.

LOSS OF HEAT.

Per sq. ft. of window and wall surface, for one degree difference in inside and outside temperatures, the loss being expressed in heat units per hour.

Character of Surface.	B. T. U. per Hour.
Window, single glass	0.776
Window, double glass	0.518
Skylight, single glass	1.118
Skylight, double glass	0.621
Brick wall, 4 inches	0.680
Brick wall, 8 inches	0.460
Brick wall, 12 inches	0.320
Brick wall, 16 inches	0.260
Brick wall, 20 inches	0.230
Outer doors	0.420
Floors, wooden beams, planked	0.083
Floors, fireproof, floored with wood	0.124
Ceilings, wooden beams, planked	0.104
Ceilings, fireproof construction	0.145
Ordinary wooden walls, lathed and plastered, sheathing 1 inch thick on studding, covered with building paper, weatherboarded	about 0.1

The thickness of the window glass matters very little. The *double glass* referred to means two sheets of glass with an air space between them.

If brick walls are made double, with an air space in the middle, the air space will reduce the loss of heat below that of a solid wall having an equal thickness of brick. The saving will be about .07 or .08 heat unit per square foot.

1567. The losses shown in the table will be increased by circumstances approximately as follows:

Where the exposure is northerly, and the winds are strong, 10 per cent.

When the building is heated during the day, and is allowed to cool off partially during the night, the exposure being moderate, 10 per cent.

Same, northerly exposure with high winds, 30 per cent.

When the building is heated occasionally, for a day only, and is allowed to freeze for intervals of several days, such as churches and audience rooms, 50 per cent.

The temperature of cellars that are not warmed may be assumed for purposes of calculation to be 32°. Vestibules and corridors which are frequently opened to the outer air, and which are not heated, may be assumed to have a temperature of 20°.

1568. In computing the loss of heat from the air within a room, all of the surfaces must be considered, the ceiling and floor as well as the ends and sides. If a room is located over a cold cellar, or a cold corridor, the cooling effect of the floor must be considered. If a room is covered with a flat roof, and is ceiled, or lathed and plastered on the rafters, the cooling effect of the ceiling may equal or even exceed that of the walls. If there is a space between the roof and the ceiling which is not wind-tight, the temperature of the ceiling should be assumed to be 10°.

1569. In computing the total loss of heat from a building which is to be warmed throughout, the interior walls, floors, and ceilings may be disregarded, and only the outer walls, windows, doors, roof, and first floor considered.

EXAMPLE.—What will be the loss of heat per hour from the rooms shown in Fig. 606, the conditions being as follows: The rooms are located in the third story of a building, the temperature is maintained at 65°, while the outer air is at zero; the floors are warm, the rooms below being heated; the walls are of brick, 8 inches thick; the ceilings are 10 feet high; the windows are all 2½ × 6 feet, with ordinary single glazing; the rooms *B*, *C*, *D* are surmounted by an attic which is not heated; the roof is an ordinary double pitched roof of slates laid on 1-inch boards; the ceilings are plastered and the joists are floored over with matched flooring; the room *A* has a plastered ceiling, but the roof is of tin, flat, inclined 2 inches per foot, the space between them being practically wind-tight; the prevailing winds are from the north. What will be the loss of heat per hour by conduction only?

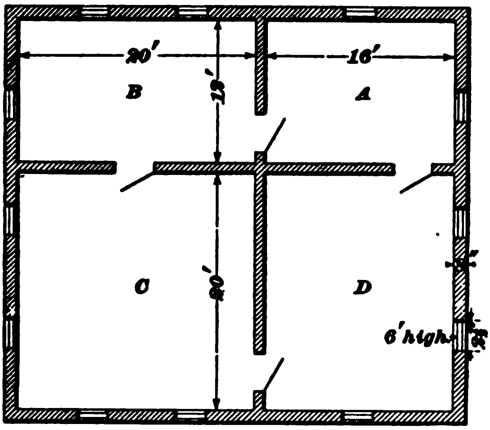


FIG. 606.

SOLUTION.—The window surfaces are 12 × 2½ × 6 = 180 sq. ft. The loss per hour will be (see Table 65)

$$180 \times .776 \times 65 = 9{,}079.2 \text{ B. T. U.}$$

The net area of exposed walls will be (20 + 12 + 20 + 16) × 2 × 10 − 180 = 1,180 sq. ft. The loss of heat per hour will be (see Table 65)

$$1{,}180 \times .46 \times 65 = 35{,}282 \text{ B. T. U.}$$

The loss through the ceilings should be computed separately, because the ceiling and roof over room *A* offer less resistance to the escape of heat than those over the other rooms. The areas of the ceilings in rooms *B*, *C*, *D* aggregate (12 × 20) + (20 × 20) + (16 × 20) = 960 sq. ft. If the attic is wind-tight, the temperature will probably be 5 to 10 degrees warmer than out of doors. The loss of heat will then be

$$960 \times .104 \times 55 = 5{,}491.2 \text{ B. T. U.}$$

There being only one thickness of roof boards, in addition to the plaster, over the room *A*, the loss of heat will be rapid, and the coefficient should be from .20 to .30 per sq. ft. per degree. The loss of heat through the ceiling of room *A* will, therefore, be about

$$12 \times 16 \times .2 \times 65 = 2,496 \text{ B. T. U.}$$

The aggregate losses are, therefore, as follows:

Windows	9,079 B. T. U.
Walls	35,282 B. T. U.
Ceilings, rooms *B*, *C*, *D*	5,491 B. T. U.
Ceiling, room *A*	2,496 B. T. U.
Total loss of heat per hour	52,348 B. T. U.

The exposure to wind is supposed to be northerly in this case; therefore, 10 per cent. should be added to this estimate. The total loss then becomes

$$52,348 + 5,235 = 57,583 \text{ B. T. U. per hour.}$$

AMOUNT OF HEAT REQUIRED.

1570. In many instances the loss of heat from the room will be partially compensated for by the heat which is emitted from gas lights, electric lamps, etc., and by the heat which is given off from the persons occupying the room. The amount of heat from these sources is about as follows:

Emission of heat from persons, lamps, etc., in heat units per hour.

	B. T. U.
Each adult person	400
Ordinary 5-foot gas burner, 15 c.p	4,800
Welsbach incandescent lamp, 50 c.p	2,000
Electric incandescent lamp, 16 c.p	220

In lecture halls and large audience rooms, the amount of heat given off by the audience and the lights may equal or exceed that which is lost through the walls and windows. When this occurs, it becomes necessary tô lower the temperature of the fresh air supply. It may even require to be reduced below the desired temperature of the room during the presence of the audience. Thus, the actual amount of heat required in any certain case may vary from hour to hour, although the atmospheric temperature is stationary.

The heating apparatus, however, must be capable of maintaining the temperature of the rooms at the desired degree without the aid of the lights and when no audience is present.

The total amount of heat to be supplied by the apparatus should, therefore, be taken as fully equal to the loss by ventilation plus the loss by conduction through the walls and windows or other cooling surfaces.

VOLUME OF HOT AIR REQUIRED.

1571. The loss of heat per hour by conduction through windows, walls, etc., being given, and also the *temperature* of the hot air supply and the desired temperature of the room, the required volume per hour may be computed by the following

Rule.—*Multiply the amount of heat lost by conduction per hour in heat units by 58, and divide the result by the difference in degrees between the given temperatures of the room and the hot air current. The quotient will be the required volume of hot air, in cubic feet per hour.*

EXAMPLE.—The loss of heat by conduction from a certain building is 200,000 heat units per hour, the temperature of the fresh hot air may be taken as 110°, and the rooms are to be maintained at 70°; what should be the volume of the hot air supply ?

SOLUTION.—$\frac{200{,}000 \times 58}{110 - 70} = 290{,}000$ cu. ft. per hour. Ans.

TEMPERATURE OF HOT AIR SUPPLY.

1572. The volume of a hot air supply is generally determined by the requirements of ventilation, and its temperature is made just sufficient to afford the amount of heat required.

The desired **volume** of the fresh air supply in cubic feet per hour, the amount of heat lost by conduction in heat units per hour, and the desired temperature of the rooms being given, the temperature which the hot air should have on entering the rooms may be computed by the following rule :

Rule.—*Multiply the amount of heat lost by conduction in heat units per hour by 58, and divide the result by the given volume of the air current. Add the quotient to the desired temperature of the room; the sum will be the required temperature of the hot air supply.*

EXAMPLE.—A certain building requires 480,000 cubic feet of air per hour, for heating and ventilation. The amount of heat lost from the rooms by conduction is 200,000 heat units per hour, and the rooms must be maintained at a temperature of 70°; what must be the temperature of the fresh air supply at entering the room?

SOLUTION.— $\frac{200,000 \times 58}{480,000} + 70 = 94.17$ degrees. Ans.

METHODS OF HOUSE HEATING.

1573. The methods of house heating now in vogue may be divided into two classes called **direct** and **indirect.** The distinction between them consists solely in the mode of supplying the heat. In the direct method, the heat is emitted from stoves or radiators contained within the room to be warmed; in the indirect method, the heat is supplied by a current of hot air which is brought in from some outside source.

Several modifications and combinations of these methods are also used. The so-called **direct-indirect** method is one in which the room is warmed by the direct action of a radiator or heater, and in addition a current of fresh air is allowed to enter the room from the outer atmosphere. This fresh air, however, is compelled to pass through the heater and become warmed before it mingles with the air in the room.

The direct-indirect system is a combination of a system of direct heating with one of direct ventilation, the ventilasion usually being limited to the room containing the heater. If there is no vent by which air may flow out of the room at the same time that the fresh air flows in, the current can not be maintained, and the heater then operates like any direct heater.

Indirect heating systems are usually combined with a system of ventilation, but are sometimes operated without it. Indirect heating is sometimes practised by means of a heater or "stack" which takes cold air out from a room and, after warming it, returns it to the same room through the ordinary hot-air flues and registers. This method is highly objectionable from a sanitary point of view, but it is sometimes used for warming hallways or large rooms which contain only a very few people. The air within a room may be heated and kept warm, without introducing any fresh air, by either the direct or indirect method. Thus, it will be seen that ventilation is not inseparably connected with either system of heating.

DIRECT HEATING.

1574. The **direct heating system** is usually operated without any provision for ventilation, and it is not suitable, therefore, for warming dwellings or rooms which are occupied by people.

Direct heating apparatus emits heat both by radiation and by conduction. But the method of warming apartments by means of radiated heat is a very poor and ineffective one. As explained elsewhere, radiant heat will not warm air directly. Air can be heated only by conduction and contact with warm surfaces; consequently, the heat which is *radiated* from the heater can only be utilized by an indirect process. It must be intercepted and absorbed by some intermediate body, which will thus become warm, and will in turn impart the heat by conduction to the surrounding atmosphere. This function is performed, in practice, by the walls of the room, the furniture, draperies, etc. The effect of the radiant heat upon them is to spoil the varnish and the glued joints, and it also shrinks and cracks the woodwork, fades the hangings and carpets, and is particularly destructive to the bindings of books.

1575. The old-fashioned low-down **grates** are probably the least efficient form of heaters now in use. They have very little heating surface and operate mainly by radiating heat from the incandescent fuel. The heat contained in the products of combustion is usually carried off into the chimney and wasted.

The same objections apply to *gas grates*, *gas logs*, and many forms of *gas stoves*. The reflecting gas stove has the additional defect of emitting strong light from a point near the floor.

Light proceeding from such a low level is very irritating to the eyes.

1576. The ordinary plain, cylindrical **coal stove** is a heating device of low efficiency. The hot products of combustion are discharged into the chimney before they have time to give off any considerable part of their heat into the room. Thus the greater part of the heat evolved from the fuel goes to waste up the chimney. These stoves are very deficient in amount of heating surface. The stove-pipe operates as a radiator, to some extent, by transmitting heat from the hot gases passing through it to the air around it.

1577. **Base heating stoves** are more efficient because they are provided with flues which compel the hot gases to circulate under the lower part of the stove before passing off to the chimney. The amount of heating surface is thus increased, and the gases are given more time in which to impart their heat to the air of the room.

1578. A **double heater** consists of a stove which is partially enclosed in a jacket. Cool air enters the lower end of the jacket, and becoming warmed by contact with the hot surface of the stove, ascends to the top and is discharged into the upper part of the room. The jacket increases the efficiency of the heater by increasing the velocity of the hot-air currents. The double heater may be easily adapted to the direct-indirect system of heating by supplying the jacket with fresh air through a duct leading from the outer atmosphere.

Double heaters might be called *furnaces*, but in practice the term is restricted to jacketed heaters of large size. They are constructed with a large amount of heating surface, so that great quantities of air may be heated.

Hot-air furnaces, steam boilers, and hot-water heaters are treated in detail later on, in separate sections.

1579. Oil and gas stoves form a class of small portable stoves which burn oil or gas, and are designed to heat single rooms. These are made singly, and also in groups; the former are called *stoves*, and the latter *radiators*. They are not usually connected to a chimney, and they mingle the products of combustion directly with the air of the room. The entire heat contained in the hot gases is expended in warming the air, and in that respect they are remarkably effective heaters. But, for warming air which is to be breathed, nothing worse could be devised. They vitiate the air very rapidly, and their use should be prohibited.

1580. All **cast-iron stoves** have one defect, which is in some cases a serious one. When cast iron is heated to a visible dull red heat, it is no longer gas-tight. Carbon monoxide will leak through it with considerable freedom. The gas appears to soak into one side of the cast-iron plate and to exude from the other, just as water will soak through a piece of blotting-paper. Wrought-iron and steel plates do not pass these gases to any noticeable extent, presumably because the metal has been changed in character during the process of manufacture. In any air-heating apparatus where the air passes over red-hot cast-iron surfaces, it is very liable to be contaminated more or less by this poisonous gas.

GENERAL REQUIREMENTS OF A HEATING SYSTEM.

1581. In order to heat and ventilate a room satisfactorily, the following desiderata are necessary:

1st. A uniform distribution of heat throughout all parts of the room, as far as possible.

2d. A thorough diffusion of fresh air throughout the level or zone in which persons breathe.

3d. A prompt and complete removal of all foul air from the room.

4th. A means of preventing all waste of heat, caused by the premature escape of the heated air.

5th. A means of avoiding perceptible currents or drafts of either warm or cold air.

1582. Bad Effects of Unequal Warming.—If the air in a room is cool near the floor and hot near the ceiling, the inmates of the apartment are likely to suffer from cold feet and congested heads. The congestion will produce headache, stupidity, and nervous irritability; and if long continued will lead to indigestion, weak sight, and general debility. It is especially injurious to school children. Study naturally produces some congestion in the head, and the evil is greatly aggravated if they are also compelled to endure unequal heating. The first effect is to dull the perceptions and render study more difficult than it would otherwise be, thus defeating the purpose for which schools are maintained.

When persons are exposed to radiant heat upon one side only, as when sitting in front of a grate or stove, they are liable to be warmed very unequally. The results are languor, drowsiness, and general depression. The effects of radiant heat on the back of a person are worse than on the front. It is not the exposure to *high* temperature merely that injures; it is the inequality of heat upon the opposite parts of the body.

1583. The **circulation of air** and consequent distribution of heat throughout a room depend greatly upon the locations of the air inlet and outlet, and upon the location of the radiator or stove relatively to the cold exterior walls.

The circulation which is caused by the introduction of warm air and the expulsion of foul air at various points is shown in Figs. 607 to 610.

1584. Fig. 607 shows the interior circulation in a room which is heated in the ordinary old-fashioned way. The hot air enters at *a* and escapes through the ventilating register *b*, which is located near the top of the wall at the opposite end of the room. The direction of the currents is shown by the arrows. The air composing the main current *c* is much warmer than that in the space *d*. There will be some circulation in this space, as shown by the dotted arrows, but it is usually very sluggish. There will usually be a layer of cold air, more or less foul, near the floor at *e*. The current of fresh hot air passes through the room so directly and quickly that it will not diffuse into the main body of air at *d* to a sufficient extent to freshen and purify it properly.

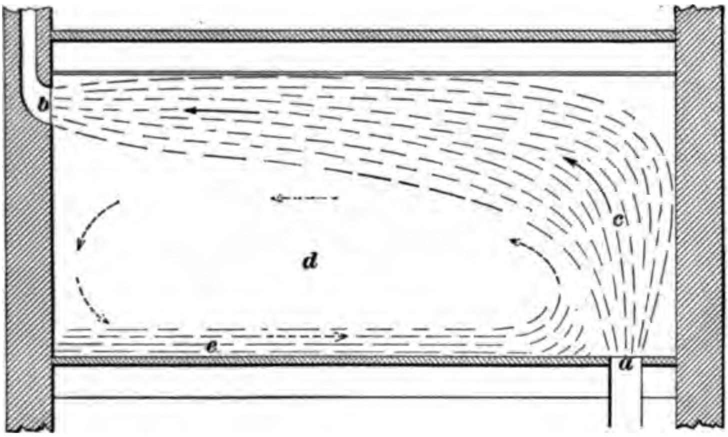


FIG. 607.

There will be a considerable difference in temperature of the air at the floor and at the breathing level, and the inmates of the room are likely to suffer more or less discomfort in consequence. The hot air escapes from the room at a high temperature, and a large percentage of the available heat is thereby wasted.

1585. In Fig. 608 the outlet *b* is brought down near the floor, the inlet remaining the same as in Fig. 607. The premature escape of the hot air is prevented and the distribution of heat is somewhat improved, but it is still quite imperfect. The momentum of the hot air as it enters through the floor register *a* causes it to pass upward to the ceiling in a compact current. The upper part of the room becomes filled with a mass of hot air, which is much warmer than the air near the floor, thus producing unequal heating as in the former case, although not quite so bad.

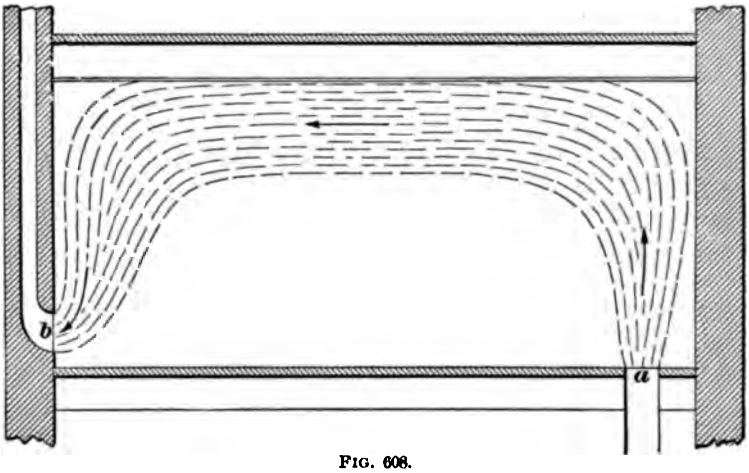


FIG. 608.

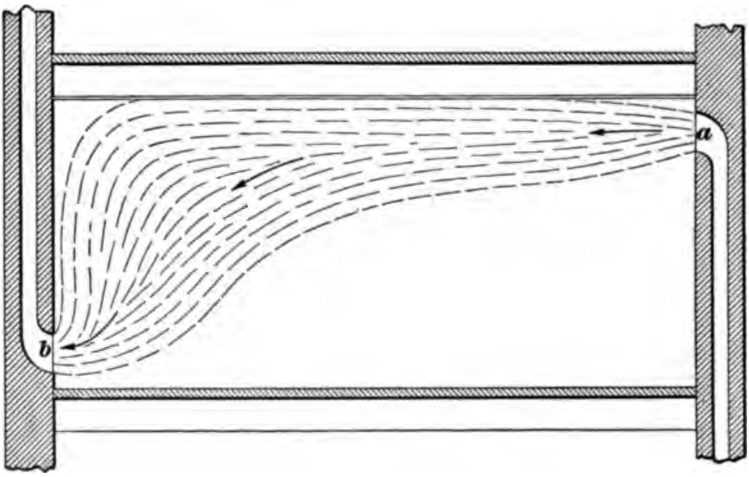


FIG. 609.

1586. In Fig. 609 the inlet *a* is raised to a point near the ceiling, and the general circulation of the hot air is sufficiently indicated in the drawing. There is but little improvement over the arrangement shown in Fig. 608, so far as the equal heating of all parts of the room is concerned.

1587. In Fig. 610 the location of the outlet is changed by placing it at or near that end of the room at which the fresh air enters. The fresh air current passes forward towards the opposite wall, spreading out and moving more slowly as it proceeds, and it gradually settles downwards and returns along the floor to the outlet *b*.

The fresh air is thus caused to travel the length of the room *twice*, instead of once, as in Fig. 609, and if the arrangements are not otherwise at fault, the distribution of heat and the freshening of the apartment will be very satisfactory.

The general circulation within a room will be greatly influenced by the nature and extent of the cooling surfaces, such as windows and exterior walls. If there is a large window in the room, the air will tend to circulate as shown in Fig. 611. Being rapidly cooled by contact with the glass, it will flow downwards with considerable velocity, and the

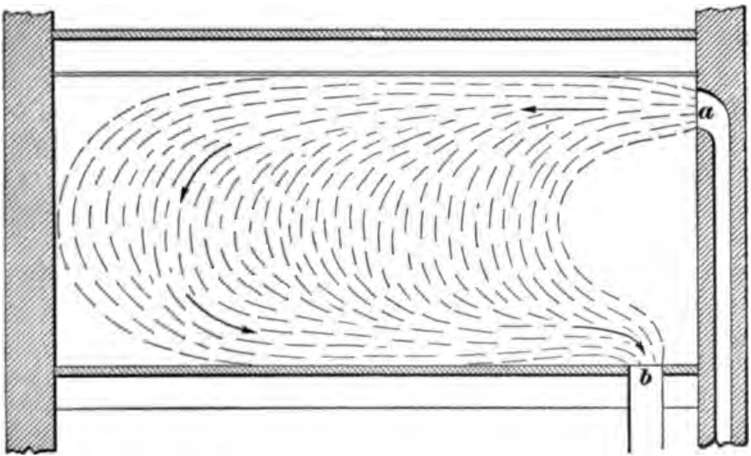


FIG. 610.

current will spread out upon the floor, thus forming a cold stratum at *a*. The upward currents of air in other parts of the room, to compensate for the downward current. will be so diffused and slow as to be imperceptible.

Now, if hot air is introduced through a floor register at *e*, or a wall register at *b*, a rapid circulation will be set up in the direction indicated by the arrows, and the difference in temperature between the upper and lower parts of the room will be increased.

The same result will follow if a radiator or stove is placed at *e*. But if the heater or hot air register is located at *d*, the circulation will be reversed in direction. The air which is cooled by the window *w* will encounter the ascending current of hot air and will be carried upwards with it. The velocity of the general circulation will then be much slower than in the former case, and the results will be more satisfactory.

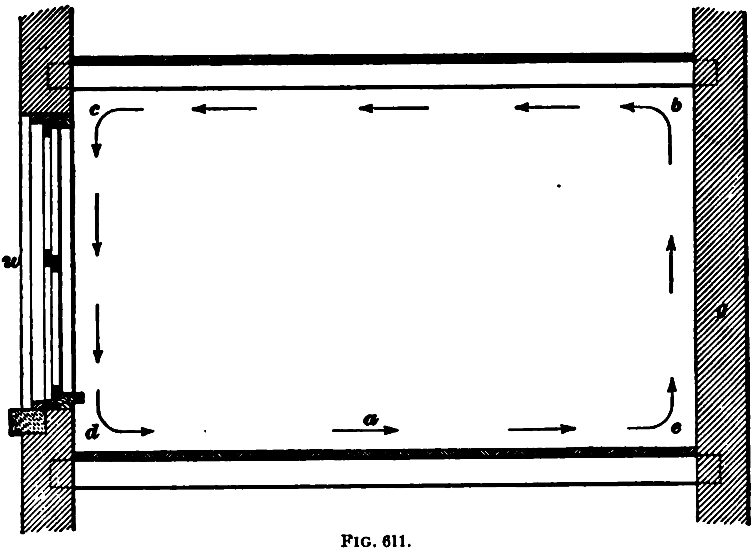


FIG. 611.

In general, the supply of hot air should be brought into the room at a level above the heads of the inmates, and not up through the floor. The object is not only to secure proper circulation, as before explained, but to prevent the incoming current of hot air from impinging upon people in the room and thus becoming a source of discomfort. The minimum height for hot-air inlets is found in practice to be about eight feet above the floor, in rooms of moderate dimensions and with currents of low velocity.

In large rooms having high ceilings, the inlets should be placed at a greater elevation, generally not less than two-thirds the height of the ceiling. In large audience rooms it is advisable to introduce the hot air at a low velocity through openings in the ceiling, and to take out the spent air through openings in or near the floor.

The number of hot-air inlets which will be required will depend upon the dimensions of the room. The air must be introduced at a sufficient number of points to secure a thorough distribution of the heat throughout the room. One inlet is usually sufficient for the rooms commonly found in dwelling-houses and offices, but in large parlors, music rooms, etc., two or even more may be employed to advantage.

1588. Hot air should not be introduced through **floor inlets,** except in a few peculiar situations.

The objections to the use of floor inlets, or registers, are that the circulation of air is usually very defective, and that they form receptacles for dirt and sweepings, etc. They also require that the carpets be cut and fitted around them, and the current of hot air which rises from them is very destructive to the pictures, draperies, and furniture which come within its influence.

They are permissible, however, in hallways and anterooms for the purpose of warming persons who have been exposed to the cold and wet. The relief afforded by standing over the register is immediate, and, to most people, very agreeable.

1589. The **outlets** for spent or foul air should be located in or near the floor, to secure proper circulation, and care should always be taken to avoid a draft or perceptible current in the vicinity of an outlet. If only a single outlet is provided, having about the same area as the inlet, the current near its orifice will have nearly the same velocity as the hot air coming from the inlet, and it will cause a draft at that point. It is, therefore, necessary that the outgoing currents be divided by increasing the number or area of the outlets sufficiently to avoid drafts of objectionable velocity.

In the case of audience rooms, the outlets should be made in the form of long, narrow slits extending horizontally at the base of the walls, or around the edges of platforms. If the floor is stepped, the outlets may be made in the risers.

1590. The plan of taking the foul air out through a large grating in the floor in the center of a hall is not a good one. The circulation is not so uniform as when the outlets are at the sides of the room, and in order to avoid perceptible drafts the grating must be made very large. The sensation of walking over a large open grating is very unpleasant to many people, and the fact that any small article accidentally dropped upon it is likely to go through and be lost is an additional reason why floor gratings should not be used.

LOCATION OF RADIATORS AND REGISTERS.

1591. It is common practice to place radiators, hot-air registers, and stoves near the inner end or corner of a room. This proceeding is wrong in principle, as explained in connection with Fig. 611.

The only advantage that can be gained by such an arrangement is that the heating apparatus is thereby concentrated near the center of the building, and consequently the amount of horizontal piping required is less than it would be if they were placed near the outer walls. A small economy in first cost is thus secured, but the efficiency of the apparatus is sacrificed, and the consequent increase in the cost of operation is a matter of much greater importance.

The main objection to placing hot-air registers and ducts in the outer walls of a building is that the hot air is likely to be chilled and the circulation thus spoiled. But this may be prevented by providing the duct with a proper covering of non-conducting material upon the outer side. The heat which escapes from the inner side passes into the rooms and does useful work.

Direct radiators should always be located near the outer walls, or where the cooling influence is greatest. Stoves should be located in the same manner as direct radiators.

Direct-indirect radiators are necessarily placed against the outer walls, and are, therefore, as a rule, located properly.

Indirect radiators should always be located at a sufficient distance below the hot-air register to cause the air to pass through them at a proper velocity. The efficiency of the radiator increases with the height of the flue, and it is a wasteful method to operate this class of radiators with short vertical flues.

If the hot air must be delivered through a floor register on the first floor, the radiator should, if possible, be lowered nearly to the floor of the basement, thus securing all the height of flue that the circumstances will permit.

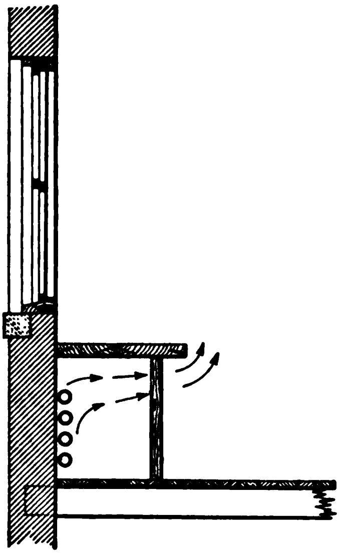


FIG. 612.

1592. In **factories and workshops** which are heated by steam pipe coils, it is customary to extend the coils along the sides of the room near the floor. There are serious objections to this plan, however.

The work benches are usually set close to the windows so as to secure plenty of light. If the pipe coils extend along under the benches, there will be a current of hot air flowing out from under them and upwards into the faces of the workmen, as shown in Fig. 612. The space under the benches is likely to accumulate rubbish and filth, and the hot air will be tainted by it. The effect upon the workmen is to produce a degree of drowsiness and languor which greatly reduces their vigor and capacity for work, and if it is long continued their health will be injured.

A better plan is to place the coils overhead, suspending them horizontally at a distance of not less than four feet above the heads of the workmen, and not less than one foot below the ceiling. The machinery, and the belting which drives it, will carry the heated air downwards towards the floor and will usually diffuse it throughout the apartment in a satisfactory manner.

HOT-AIR FLUES AND REGISTERS.

1593. The carrying capacity of a flue or duct is controlled by the temperature of the hot air and the height of the flue, in the same manner as a chimney. A flue which extends to the third story of a building will discharge more air per minute than a similar flue which discharges at the second or first floor. This is because the column of hot air extending to the third floor is higher than the others, and consequently the upward pressure is greater, as explained in Art. **1431.**

In practice, the flow per minute will be considerably less than the theoretical amount, because of the frictional resistance in the flues.

The allowance to be made for friction varies for each situation. In the following table, an allowance of 50 per cent. has been deducted from the theoretical flow; this will be sufficient for all ordinary circumstances. It should be borne in mind that the volume of flow shown in the table can not be attained unless the air in the room is permitted to escape freely and as rapidly as the fresh warm air is inclined to come in.

TABLE 66.

1594. Flow of air in flues by natural draft in cubic feet per minute. Area of flue 1 sq. ft.

Difference in Temperature F°.	Height of Flue in Feet.								
	10	15	20	30	40	50	60	80	100
10	108	133	153	188	217	242	264	306	342
15	133	162	188	230	265	297	325	375	420
20	153	188	217	265	306	342	373	435	485
25	171	210	242	297	342	383	420	485	530
30	188	230	265	325	375	419	461	530	594
40	216	265	305	374	431	482	529	608	680
50	242	297	342	419	484	541	594	680	768
60	266	327	376	460	532	595	650	747	842
70	288	354	407	498	576	644	703	809	910
80	308	379	435	533	616	688	751	866	972
90	326	401	460	565	652	728	795	918	1,029
100	342	419	484	593	684	765	835	965	1,080
125	384	470	541	664	766	857	939	1,085	1,216
150	419	514	593	726	838	937	1,028	1,185	1,325

The *difference in temperature* given in the table is that existing between the outer atmosphere and the average of the air in the flue.

Each register should be supplied by an independent vertical duct. Sometimes it is practicable to supply two or more registers, which are located at the *same level*, by means of one duct, but generally such arrangements are liable to be unsatisfactory.

It is difficult and usually impracticable to supply registers which are on different floors from a single vertical flue. The upper registers will discharge an undue proportion of air, and the flow from the lower registers will be too small unless some means is employed to regulate the flow.

Several vertical ducts may be supplied by a single horizontal main pipe or flue, although they vary in height. The flow in each duct may be regulated by partially closing the opening at its foot.

The cooling effect of the surroundings of a hot-air duct should always be taken into consideration when determining its dimensions. In a long duct the average temperature is likely to be lower than in a short one, because of the greater loss of heat. The reduction of the average temperature decreases the rate of flow, and the dimensions must be modified accordingly.

Hot-air pipes are commonly made of bright tin, it being supposed that the bright surface of the metal will prevent the escape of heat to a considerable degree. The retarding influence of the bright surface is, however, quickly spoiled by a coating of fine dust which is deposited on it, and the chief use of the tin coating is to prevent rust and to preserve a smooth surface. The best way to prevent loss of heat is to cover the pipes with non-conducting materials.

The area of a hot-air register should be sufficient to permit the desired quantity of air to pass into the room at a velocity not exceeding four feet per second.

1595. The velocity of the air in the flues may be as great as desired, or as the circumstances will permit, but the current issuing from the register must be reduced to, or less than, the velocity given. This may be done by enlarging the flue where it approaches the register. The velocity of the current in any particular part of the flue should be inversely proportional to the area of the flue at that point. Thus, if the air in a flue having one square foot of sectional area moves with a velocity of eight feet per second, its velocity will be reduced to four feet per second in any part of the flue where the area is increased to two square feet.

The enlargement of the flue at the register box should be made gradually, and with round corners, if practicable.

1596. The following table shows the net or effective area of ordinary square and round registers:

TABLE 67.

AREA OF REGISTERS.

Square Registers.

Size of Opening.	Net Area.	Size of Opening.	Net Area.
Inches.	Square Inches.	Inches.	Square Inches.
6 × 10	40	14 × 22	205
8 × 10	53	15 × 25	250
8 × 12	64	16 × 24	256
8 × 15	80	20 × 20	267
9 × 12	72	20 × 24	320
9 × 14	84	20 × 26	347
10 × 12	80	21 × 29	400
10 × 14	93	27 × 27	486
10 × 16	107	27 × 38	684
12 × 15	120	30 × 30	600
12 × 19	152		

Round Registers.

Diameter of Opening.	Net Area.	Diameter of Opening.	Net Area.
Inches.	Square Inches.	Inches.	Square Inches.
7	26	18	169
8	33	20	209
9	42	24	301
10	52	30	471
12	75	36	679
14	103	48	1,000
16	134		

PREVENTING LOSS OF HEAT.

1597. No material is known which will totally obstruct the passage of heat by conduction. There is, however, a great difference in the conductivity of materials, and those which conduct heat very slowly are called by the general name of **non-conductors.**

An air space is usually considered to be a good non-conductor, but an air space alone is of little use, because of the circulation of air in the space.

The amount of circulation will largely depend upon the size of the enclosure, and, if free circulation is permitted, the diffusion of heat throughout the mass of contained air will be quite rapid. Thus, the rapidity of the transfer of heat from the hot side of an air space to the cooler side will be proportional to the amount of convection or circulation permitted within it. Therefore, when an *air space* is used to prevent loss of heat, it should be subdivided into very small cells.

The efficiency of an air space for the purpose of retaining heat is not very large when compared with coverings composed mainly of felt or fibrous materials.

Much of the obstruction to the passage of heat which is commonly ascribed to air spaces is really due to the increase in the number of surfaces through which the heat must be absorbed and emitted.

Whenever heat is transmitted from a dense medium to a lighter one, or the reverse, it is always retarded. Thus, when heat passes through a loose bundle of fibers, or through a mass of cellular material, it is absorbed and emitted from the opposite surface of the fibers or cells a great many times; consequently, the total retardation is great.

There is also another cause which reduces the comparative conducting power of fibrous or porous materials. The heat-conducting capacity of a solid bar is proportional to the area of its cross-section, and the low conducting power exhibited by the fibrous material is partly due to the fact that the actual sectional area of the fibers, in any given cross-section, is much less than that of a solid block of similar size.

1598. In a general way, the efficiency of non-conducting materials is proportional to their lightness per cubic foot.

Thus, heat passes through a solid plate of glass with comparative freedom, but a layer of "mineral wool" or "slag wool" (which is merely glass blown into fine threads) of the same weight per square foot of surface exhibits very much smaller conducting power.

Any fibrous or porous non-conducting material will become a better conductor if it is compacted by pressure. Therefore, in applying soft, fluffy materials care must be taken to avoid compacting them too much, and also to prevent them from sagging and matting together while in use.

The materials used as non-conductors vary greatly in durability, and this fact should be carefully considered when estimating the saving that may be accomplished by using them.

Many animal substances, such as hair, wool, feathers, eiderdown, etc., are excellent non-conductors, but are unable to endure a temperature above 150° for any considerable time without becoming brittle and matting together. Felt made of hair or wool is slowly charred and destroyed by the heat of ordinary high-pressure steam pipes, and if used on such pipes it should be applied only as an outer coating over some harder and more durable material, such as "fossil meal" cement or asbestos cloth.

All non-conducting coverings should be well protected against displacement and the entrance of either air or moisture. A covering of painted canvas, well secured by copper wire, is usually sufficient for pipes which are not exposed to the weather, but in all exposed places great care should be taken to make the outer casings perfectly waterproof.

1599. Much of the inefficiency of non-conducting coverings is due to the lack of attention given them. Little can be expected from even the best of non-conductors if they are allowed to become loose and get out of place, or if air currents can circulate between them and the pipe. They should be inspected at least once a year, and all shrinkage taken up, and the outer casing also kept in good order.

TABLE 68.

NON-CONDUCTING COVERINGS.

Kind of Covering.	B. T. U. Transmitted per Hour per Sq. Ft. Surface, per Degree Difference of Temperature.	Loss Per Cent.
"Manville" sectional and hair felt	0.2169	8.00
Rock wool	0.2556	9.50
Mineral wool	0.2846	10.50
"Champion" mineral wool	0.3166	11.72
"Manville" wool cement	0.3448	12.77
"Manville" sectional	0.3496	12.94
Magnesia	0.3838	14.20
Hair felt	0.4220	15.62
Fire felt	0.5023	18.60
Fossil meal	0.8787	32.54
"Riley" cement	0.9531	35.30
Bare pipe	2.7059	100.00

The efficiencies of the various non-conductors now on the market vary much less than what is usually stated in advertising literature.

It has been found by experiment that for each material there is a certain thickness which gives the best result, and that a further increase in thickness adds but little to the efficiency of the covering. Therefore, data respecting non-conducting materials, which are based upon a uniform thickness of one inch, are liable to be misleading.

The preceding table shows the actual results of experiments with various materials, when used to cover an eight-inch wrought-iron steam pipe.

The thickness of the covering was, in each case, that recommended by the makers.

REGULATION OF TEMPERATURE.

1600. The method which may be used for controlling the temperature of the air within a building depends upon the system of heating which is employed, and also upon the heating agent, whether steam, hot water, or hot air. The emission of heat from a *steam* radiator may be graduated in several ways:

1st. By dividing the radiator into several independent sections and admitting steam to more or less of them, as desired.

2d. By admitting steam at full pressure and shutting it off again at moderate intervals, in regular alternation; the *average* temperature of the radiator thus obtained depends upon the relative length and frequency of the intervals.

3d. By varying the pressure of the steam.

1601. The first method is a good one and is used to some extent, but its general use is prevented by the lack of suitable apparatus. The expense and bother of adapting the varieties of radiators now on the market, and making the necessary connections with the valves of the ordinary kind, are almost prohibitory.

The second method is usually carried out by means of automatic valves, which are similar in general principle to pressure-reducing valves.

The third method is commonly applied by varying the intensity of the fire under the boiler, or by the use of an automatic pressure-reducing valve, the adjustment being varied to give the desired steam pressure.

The emission of heat from a *hot-water* radiator may be graduated by adjusting the inlet valve, thus controlling the amount of hot water which flows through it.

When the *indirect heating* system is employed, the temperature of the air which is delivered by the apparatus may be controlled, not only by modifying the emission of heat from the radiators, but by mixing the hot air with a sufficient quantity of cold air to obtain the temperature desired. The former method is so slow in operation that it is not generally satisfactory; but the latter method produces the desired result very promptly and is also easy to manage.

When hot-air *furnaces* are used for heating, the methods of controlling the temperature by mixing or by operating the registers are the only ones which will give satisfaction. Regulation by varying the fire, even although it is most commonly done, is altogether too slow and uncertain.

MIXING VALVES.

1602. The *volume* of the fresh air supply is usually fixed by the requirements of ventilation, and it is usually so large that the temperature must be only a few degrees above the desired temperature of the rooms. The apparatus which would be necessary to warm such a large volume of air to the moderate degree required would be very large and expencive. The difficulty is overcome by heating a smaller volume of air to a high degree, and mixing it with a sufficient quantity of cold fresh air to produce the required volume and temperature.

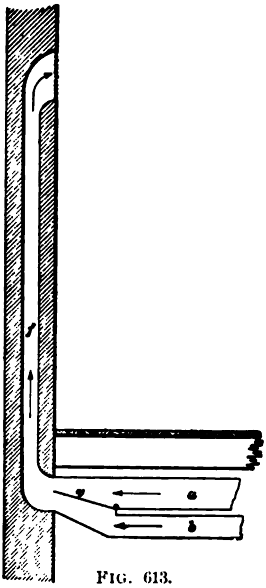


FIG. 613.

1603. The mixing is usually accomplished by means of what are called **mixing valves.** Fig. 613 shows the mode of applying a mixing valve to a duct leading from the mains of an ordinary forced blast system. Hot air flows through the duct *a*, and cold air is supplied by the duct *b*. The opening of *b* into *a* is covered by a valve *v*, which is hinged as shown. By moving the valve up or down, the proportions of hot and cold air which pass into the flue *f* may be varied as desired. As the opening for cold air is increased, the flow of hot air is restricted, and *vice versa*, but the valve does not operate to increase or diminish the volume of the current passing up the flue *f*.

1604. Fig. 614 shows the application of a mixing valve to an indirect radiator. The radiator is enclosed in the case

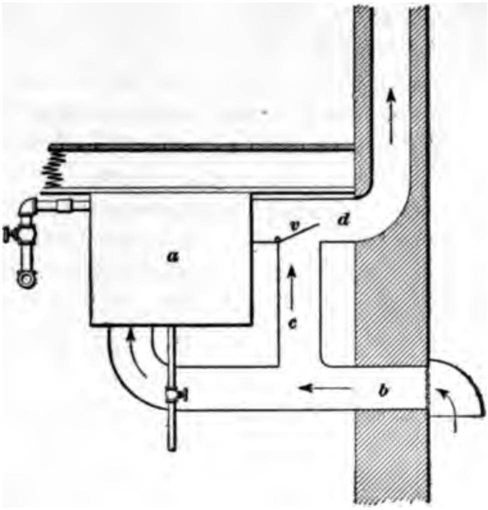


FIG. 614.

a, and is supplied with fresh cold air by the duct *b*. Warm air is delivered though *d* into the flue as shown by the arrow. The duct *b* is connected to *d* by a by-pass pipe *c*, and the opening is controlled by a valve *v* which is hinged as shown. This valve permits more or less cold air to pass directly into the flue without passing over the radiator. The flow of air through the radiator box *a* is checked to the extent that air is allowed to pass up the pipe *c*. The area of the opening of the valve *v* usually does not require to be more than ⅓ to ½ that of the vertical duct.

The mixing valve should be located at the foot of the vertical duct, and it may be operated from any floor by means of suitable connections. These are usually made of brass wire and chain, brass being used to avoid breakage by rusting. If desired, the connections may pass down through the flue.

All mixing valves should operate to change the *proportions* of the hot and cold air, without affecting the volume of the currents passing into the rooms.

AUTOMATIC TEMPERATURE REGULATORS.

1605. Regulators which are commonly employed for automatically controlling the operations of a heating apparatus are arranged either to operate the furnace dampers and thus control the fire, or to vary the adjustment of a mixing valve, or to open and close or regulate the apertures of valves, which govern the flow of the heating fluids.

There is a class of **damper regulators** which are operated by the pressure of the steam in the boiler, but they are useful only for regulating combustion of the fuel and so maintaining a constant pressure of steam.

1606. There is another class of regulating apparatus which is operated by the heat of the air in the room to be warmed. These are called by the general name of **thermostats.**

A thermostat operates by the expansion or bending of compound metallic bars, such as those employed in metallic thermometers, etc., or by the expansion of a very volatile liquid which is contained in a flexible metallic case. The motion generated by these thermometric elements is usually too small to be used directly for operating valves or dampers. Sometimes the motion is increased sufficiently by means of levers; but in most cases, the heat-regulating valves are moved by the assistance of other forces, such as clockwork, compressed air, water pressure, steam, or electricity.

The internal construction of a thermostat which operates by the expansion of a volatile liquid is shown in Fig. 615. It consists of a metal shell *c d* which is divided into two chambers, *a* and *b*, by the flexible corrugated diaphragm shown. The chamber *b* is partly filled with the liquid as shown. The pressure of the vapor above the liquid is always proportional to the temperature. Naphtha is an excellent material for this purpose, because the pressure of the vapor at temperatures of 70° or 80° amounts to several pounds per square inch, and thus furnishes sufficient force to operate ordinary dampers, etc.

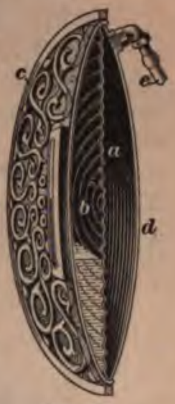


FIG. 615.

When the temperature of the air around the thermostat increases, the vapor pressure rises correspondingly and forces the diaphragm towards the chamber *a*. The movement of the diaphragm may be utilized in any convenient manner to operate valves, etc. If the valve or damper moves easily, it may be operated by means of a diaphragm motor such as is shown in Fig. 616. The chamber under the diaphragm *a*, Fig. 616, is connected to the chamber *a*, Fig. 615, by means of a tube *e*, and all are filled completely with some suitable liquid, such as oil or water.

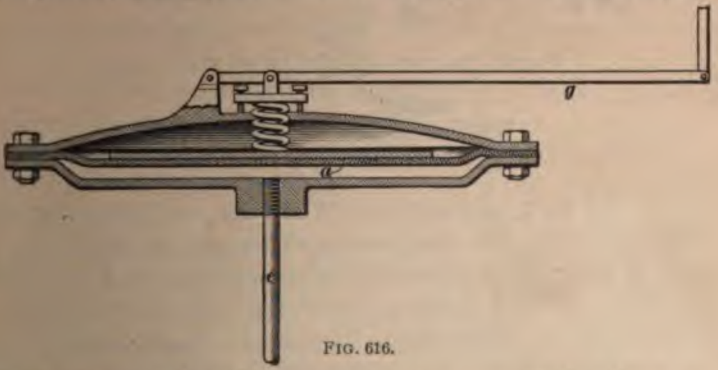


FIG. 616.

The motion of the thermostat diaphragm will thus be transmitted to the motor diaphragm *a* and lever *g*, Fig. 616, which will increase it sufficiently to operate an ordinary damper.

1607. When the valves or dampers require more power to operate them, the necessary force may be secured by the mechanism shown in Fig. 617. The pressure from the thermostat passes through the pipe *e* into the chamber *h* and depresses the diaphragm *i*. The motion is transmitted by the plate *j*, stem *k*, plate *l*, diaphragm *m*, and plate *n*, to the stem *o* of a small valve *p*, which admits compressed air, water pressure, or steam from the pipe *q* to the chamber *r*. This motor fluid is transmitted by the pipe *s* to some kind of a motor, such as shown in Fig. 616, or to a cylinder or piston, as the work may require. When the temperature at the thermostat falls and the pressure decreases, the diaphragms *i* and *m* are raised automatically by means of the lever *t* and the spring *u*, thus allowing the spring *v* to close the valve *p* and shut off the motor fluid. The small exhaust valve *w* is at the same time lifted; this allows the charge of motor fluid to escape from the apparatus, and thus permits the dampers, etc., to be moved back to their original positions by suitable counterweights. This apparatus can be adjusted to use a motor fluid of any desired pressure, so as to control

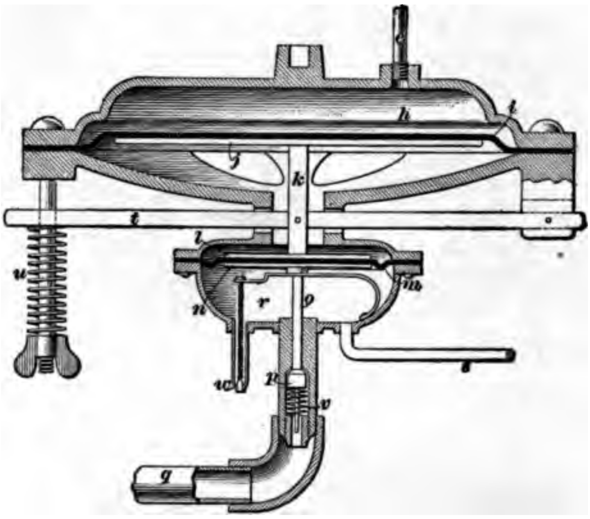


FIG. 617.

valves and dampers which require great power to move them.

The apparatus shown in Fig. 617 may be used directly as a thermostat by pouring the expansible liquid into the chamber *h*. The power delivered through the pipe *s* may be used to operate a whole group of valves or dampers simultaneously, if desired.

1608. There are also many other devices, electrical, pneumatic, etc., for the same general purpose, having various degrees of merit, but it is unnecessary to describe them here.

Thermostats when in use are usually covered with an ornamental grille, and are attached to the side walls of the room. Care must be taken in locating them to secure a position where the temperature will be the average temperature of the room, or nearly so. Therefore the vicinity of hot-air inlets or foul-air outlets should be avoided.

METHODS OF MOVING AIR.

1609. The movement of air which is required for the purposes of heating and ventilation may be accomplished by means of **natural draft** or by **forced draft.**

In both systems, the power employed to move the air is derived from heat. In the former system, it is applied directly to the air to expand it and reduce its weight, so that the colder and heavier atmosphere will displace the warmer air and drive it through the flues, as desired. In the latter system, the heat is first converted into mechanical power through the agency of a boiler and engine, and is then applied to moving the air by means of a fan. Of course, the conversion of heat into power is attended with considerable loss; but after making all proper allowances for imperfections of machinery, etc., it is found that, in order to move a given quantity of air, the former system requires about one thousand times as much heat as the latter. This is illustrated by the following

EXAMPLE.—It is required to move a quantity of air amounting to 100,000 cubic feet per minute, at a pressure of .3 inch of water; what will be the amounts of heat required to accomplish the work by means of a vertical flue 75 feet high, the atmosphere being at zero, and by the application of a good fan, the conversion of heat into power being theoretically perfect?

SOLUTION.—The total weight of a column of air which is 75 feet high must be reduced by an amount equal to .3 inch of water, or 1.56 pounds per square foot. The air when heated must weigh

$$\frac{75 \times .08635 - 1.56}{75} = .0655 \text{ lb. per cu. ft.}$$

Referring to Table 55, Art. **1423,** we find that this weight corresponds to a temperature of about 150°.

The amount of heat required will, according to rule, Art. **1365,** be

$$100{,}000 \times .08635 \times .2375 \times 150 = 307{,}620 \text{ B. T. U.} \quad \text{Ans.}$$

The mechanical power required will be

$$100{,}000 \times 1.56 = 156{,}000 \text{ ft. lb. per min.}$$

Converting this into heat units, we have

$$\frac{156{,}000}{778} = 200 \text{ B. T. U.} \quad \text{Ans.}$$

1610. In the given case, the amounts of heat required by the two systems for the sole purpose of moving the air have a ratio to each other of about 1,500 to 1. This ratio increases rapidly as the required draft pressure is increased.

Thus, it will be seen that, when any considerable draft pressure is required, it is much cheaper to use a fan or blower than to employ a tall chimney, and that the practice of heating the air in foul-air flues or ventilating stacks, in order to create additional draft, is a very expensive and wasteful proceeding.

The mechanical apparatus usually employed for moving air in large quantities, at the low pressure required for heating and ventilation, consists chiefly of *steam-jet blowers* and *fans*. Large *rotary pumps*, frequently called "positive blowers," are sometimes used, but fans are to be preferred in nearly all cases.

STEAM-JET BLOWERS.

1611. A **furnace blower** is shown in Fig. 618 which is especially designed for blowing fires, but it can be readily adapted to other work. Steam enters through the pipe *l* and issues in jets from a large number of fine holes which are drilled in the edge of the ring *r*. This ring is hollow and is made oval in section so as to permit as little obstruction to the air current as possible. Each jet of steam drags air along with it through the shell *t* and forms a stream of mingled air and steam, the several streams blending into one solid current before leaving the nozzle *s*.

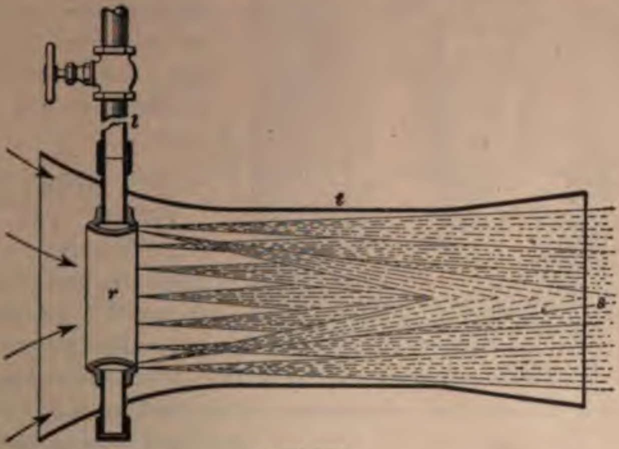


FIG. 618.

1612. A **chimney blower** is shown in Fig. 619, which is designed for increasing the draft of chimneys, etc. The steam is introduced through a single nozzle *a*, which delivers it in an annular jet inside of a small cone *b*. The steam issues at a high velocity and drags with it a considerable quantity of air. The mingled air and steam are discharged into the cone *c* at a reduced velocity. Here the current takes up more air and discharges into the next cone *d*, and as it passes through the successive cones *e*, *f*, and *g*, its volume is augmented and its velocity correspondingly reduced, until it issues from *g* with a large volume and moderate velocity.

Steam-jet blowers are capable of producing any pressure of blast up to 2 inches of water, and may be operated with steam of almost any pressure above the atmosphere. In order to secure the best results, they should be specially proportioned to suit the work and the available steam pressure.

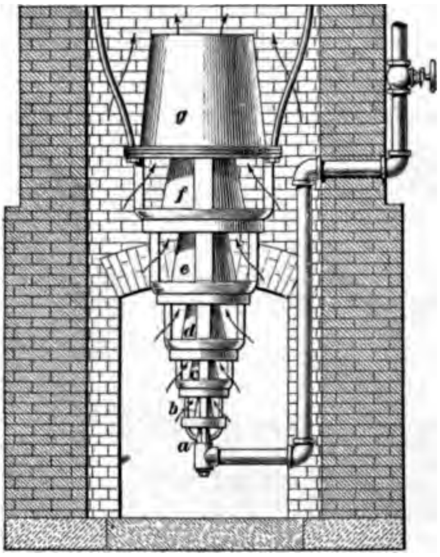


FIG. 619.

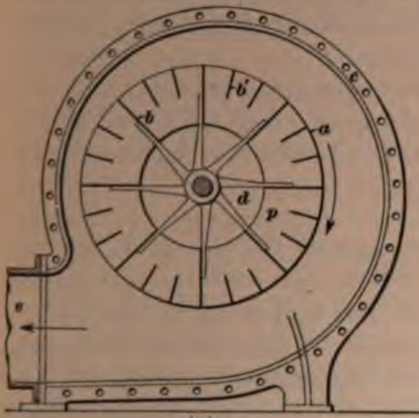
FANS.

1613. The general construction of a **centrifugal fan** is shown in Figs. 620 and 621. It consists of a wheel *a*, which revolves swiftly within a circular casing *c*, which has a number of internal vanes or blades *b*, *b'*. Air enters the casing at the central opening *d* and is expelled through the nozzle *e*.

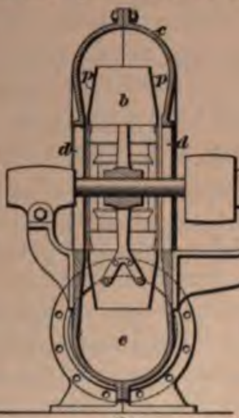
The only effect which can be produced by a fan is a greater pressure of air at the outlet than at the inlet. In this variety of fan the work is accomplished solely by *centrifugal force*. As the wheel revolves, the air in the interior is thrown by centrifugal force into the outer part of the casing, and the wheel turns so swiftly that the air can not surge back again.

In consequence of the partial removal of the air from the central to the outer part of the fan, the pressure of the air at the center diminishes accordingly. If the inlet be open, the atmosphere will rush in and restore the pressure to the normal.

1614. The distinction commonly made between **exhaust fans** and **pressure fans** depends wholly upon the manner in which they are employed. When the air duct is connected to the inlet of the fan, the pressure of the air which passes through it will always be below that of the atmosphere. The fan is then called an exhaust fan. On the contrary, when the air is forced through a duct which is attached to the outlet of the fan, the pressure of the air will always be above that of the atmosphere and the fan is then called a pressure fan.



(a)
FIG. 620.



(b)
FIG. 621.

The construction of the fan is substantially the same in both cases, and the mode of operation is always the same.

The pressure of the blast depends chiefly upon the velocity of the wheel, measured at the rim.

The volume of the blast depends upon the amount of air that can be induced to flow into the wheel through the inlet.

The size of the inlet opening must be proportioned to suit the volume and velocity of the inflowing air; it bears no relation to the diameter of the wheel.

The diameter of the wheel should always be made large enough to secure the desired velocity at the rim with a moderate rotative speed. There is much less waste of power due to the eddying of air between the blades in a large wheel than in a small one. Therefore, a given volume and pressure of blast may be produced much more economically by a large wheel rotating at a moderate speed than by a small wheel rotating at a higher speed. The small wheel must rotate faster to secure the same velocity of rim and thus generate the required pressure.

The wear and tear on the belting, countershafts, and bearings will be greatest with the small wheel. The small wheel will also make more noise than a large one doing the same work.

1615. The **power required** to drive a fan, in addition to that consumed in friction and internal waste, will be equal to the volume of air delivered from the nozzle, in cubic feet per minute, multiplied by the difference between the pressures at the inlet and the delivery, in pounds per square foot.

If the fan delivers no blast, the air whirls around idly in the casing, and the consumption of power is limited to the friction of the air and of the machinery.

When air enters a fan wheel, it moves parallel with the shaft, and is required to change its direction and move radially.

The width of the wheel at the inlet should be sufficient to permit the entering air to change its direction without too much abruptness.

For all moderate or low pressures, the blades of the wheel should be radial.

For higher pressures, such as are commonly used for melting metals, etc., they may be curved slightly, the driving side being convex. The object sought by curving the blades is to reduce the eddying of air at the back of the blades, which consumes and wastes a considerable percentage of the power applied.

The length of the blades should not exceed one-fourth of the diameter of the wheel, and they may, in many instances, be made much shorter.

The wheel is generally constructed as shown in Figs. 620 and 621, with a few blades extending inward to the edge of the inlet opening, several shorter blades *b'* being interposed at the rim.

The sides of the wheel should be enclosed, as shown, to prevent the air from escaping past the edges of the blades and thus forming useless eddies.

The side plates *p* may be made somewhat conical, mainly for the purpose of stiffening the wheel.

The casing *c* should afford plenty of space into which the air may escape from the rim of the wheel, and it should not approach the sides of the wheel too closely, except at the rim of the inlet opening. The area of the cross-section at any point should not exceed the area of the discharge nozzle.

The air is whirled around in the casing very rapidly, although at a much lower speed than the wheel; therefore, the interior surface should be smooth and free from all obstruction.

The outlet nozzle may be directed horizontally or at any desired angle, and care should always be taken in purchasing fans to have the outlet turned in a proper direction, so as to avoid all unnecessary turns or elbows in the connections.

The outlet nozzle should always extend at a tangent to the case, as in Fig. 623, and should never extend radially, as in Fig. 622. The casing should be set eccentrically with the wheel, as shown in Fig. 623, and not concentrically, as in Fig. 622.

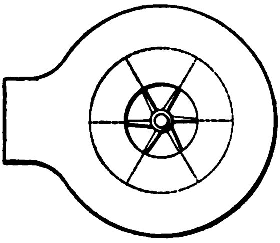


FIG. 622.

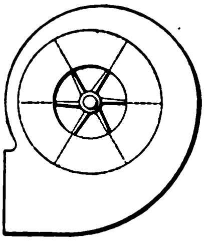


FIG. 623.

1616. The propelling wheel or **disk fan**, Fig. 624, is composed of a number of vanes *b* which are attached to a shaft *c* and set at an angle to the shaft as shown. They are rotated rapidly within the casing *a*, and while they whirl the passing air, the centrifugal force thus generated is largely wasted and the principal effect is exerted by the inclined faces of the vanes which press the air forward.

This variety of fan applies power to very poor advantage, and is the most wasteful and inefficient form in use. It is not capable of producing any considerable difference of pressure, and is more useful for agitating air than for forcing a current.

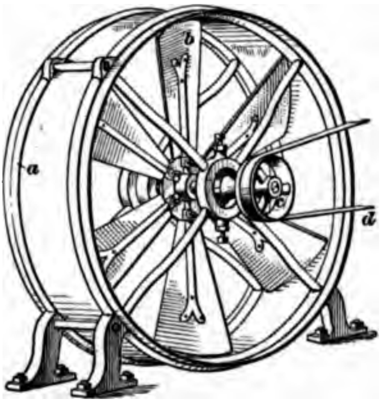


FIG. 624.

It should never be employed for moving the main air current in heating or ventilating operations.

1617. When small fans are driven by horizontal belting, they should be mounted on a sliding bed so that the belts may be tightened by shifting the fan slightly.

Two fans should not deliver into the same conduit, unless one is to be used only as a reserve for the other. If the blast pressure in the conduit exceeds the pressure produced by the fan, the blast will blow back through the fan wheel and will escape at the inlet, notwithstanding that the fan continues to run at full speed. For instance, suppose a fan producing six ounces of blast is connected to a conduit or main containing air at a pressure of ten ounces, produced by some other blower. Then the blast will blow back through the fan and will waste until the pressure falls to six ounces. The fan connection is virtually a leak in the main, and the utmost that the fan can do is to stop the leak to the extent of six ounces.

Under these circumstances the fan does not deliver any air into the main, and the other blower must supply all that is required.

Therefore a system of air supply should be driven by one fan, if possible. If it is too large for one fan, it should be divided into smaller but independent systems.

Of course, two or more fans of equal power may be coupled if they are driven by the same countershaft, or are otherwise provided with means for maintaining an equality of speed and pressure.

STEAM HEATING.

STEAM GENERATORS.

1618. The process of making steam consists in transforming water from the liquid to the gaseous condition. This can be accomplished only by the application of heat. In order to perform this work efficiently and rapidly, it is necessary that the boiler should have good **internal circulation,** so that the water may be brought into actual contact with the various portions of the surface to the greatest practicable extent.

The boiler must be made of material which will *transmit* heat readily, and the parts must be so arranged as to *absorb* the maximum amount of heat from the hot gases passing over them. It is important, also, that the parts be so arranged that they can easily be kept clean and in good condition for the transmission of heat.

The boiler must be designed in a manner that will ensure **safety,** not only under the strain of ordinary regular working, but also when worn by long service or when neglected and so allowed to get into a bad condition. The greatest danger to contend with, however, in many cases, is ignorance on the part of the persons in charge of the boiler.

CIRCULATION.

1619. The circulation of the water within a steam generator is due to two causes: first, the difference in density of the water in the various parts of the apparatus, and, second, the buoyancy of the steam. The steam is generated upon the surface of the hot plates or tubes, in the form of bubbles. These are much lighter than the water surrounding them, and, consequently, they move rapidly upwards

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until they escape from it at the surface. Being generated in great numbers, they flow upwards in streams and carry the water along with them, thus causing a rapid and forcible circulation of the contents of the boiler. Of course, if there is an upward current of water in one part of the apparatus, there must be a return current of equal magnitude in some other part.

In order to secure a high degree of efficiency, it is necessary that the parts of a boiler be so arranged that the mingled steam and water may flow upwards and away from the heating surfaces with entire freedom, and that the water, after parting with the steam bubbles, may flow back to the heating surfaces by a route which will avoid all interference with the ascending currents.

If the flow of the ascending currents is impeded or obstructed by reason of insufficient passageways, so that the steam can not freely escape from the water, there is danger of the water being lifted up or forced out of contact with the heating surface. This state of affairs may last from a few seconds to many minutes, according to the lack of skill shown in the design of the boiler.

The steam is incapable of taking up heat as rapidly as the water; consequently, plates or tubes which are covered only by steam instead of water are likely to be quickly overheated. When the water flows back upon them, they are cooled so suddenly that there is danger of cracking the metal, with possibly serious results. The production of steam in such a boiler will be irregular and spasmodic, even with clean water; but, if the water is inclined to foam the evil will be aggravated to a dangerous extent.

1620. The types of boilers which are most liable to have this defect are the **return tubular** and the **vertical tubular** boilers, and it generally results from the tubes being placed too close together. Some varieties of water-tube boilers are also very faulty in this respect.

1621. **The objects of circulation** are as follows:

First. To keep the heating surfaces covered with water at all times, thus preventing any part from becoming overheated or burned, and securing regularity and steadiness in the generation of steam.

Second. To equalize the temperature throughout all parts of the boiler, thus preventing any unequal heating and consequent straining of the structure.

Third. To keep the heating surfaces constantly and abundantly supplied with fresh water which is in a condition to take up more heat, thus maintaining the greatest practicable difference of temperature between the water on one side of the metal and the hot gases on the other.

Fourth. To sweep the heating surfaces clean of all mud and other deposits, thus keeping them in the best condition for the transmission of heat.

1622. Aids to Circulation.—Various mechanical aids have been devised to assist the circulation within boilers. These consist mainly of *circulating tubes*, *baffle plates*, and special *return tubes*.

1623. Fig. 625 shows the mode of applying a **circulating tube** to an ordinary "drop" or depending water tube. The drop tube A is attached to the crown sheet C of the boiler below the water line and hangs down over the fire, thus being surrounded by hot gases. Steam is generated rapidly upon its inner surface, and the mingled steam and water flow swiftly upwards. A return current of water flows downwards through the tube B, thus securing a rapid and positive circulation. The inner tube merely serves as a partition between the ascending and descending currents, and prevents them from interfering. If it were

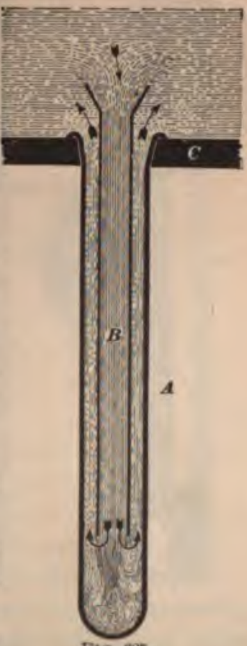

FIG. 625.

absent, the steam bubbles would be liable to combine and form large bubbles which would completely fill the bore of the drop tube, and would lift the water out of the tube in escaping. Then the water would surge back into the hot tube, and again be expelled by another rush of steam. Thus, the production of steam would be very spasmodic, and the tubes would soon be destroyed.

The *area* of the circulating tube *B* should be about one-third that of the outer tube *A*. The space below the end of the inner tube should be about equal to the diameter of the outer tube.

Fig. 626 shows a construction suitable for drop tubes which are heated mainly upon one side, as in the boiler shown in Fig. 649. The tube *a* is divided into two channels by means of a partition *b*, which extends nearly to the bottom end, as shown. The water ascends in the channel next the hot side of the tube and returns downwards in the other channel. At (*a*) is shown a section of the tube, taken on the line *x y*.

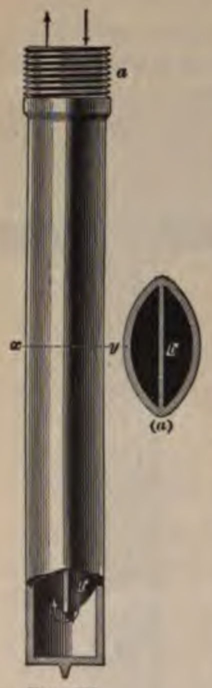

FIG. 626.

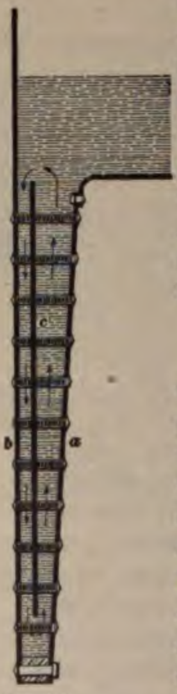

FIG. 627.

1624. Baffle plates are partitions or deflecting plates, which are set up at various points in a boiler for the general purpose of separating the currents, which might otherwise conflict. Fig. 627 shows the manner of applying a baffle plate to a boiler having an internal fire-box. The inner plate *a* is exposed to the intense heat of the fire, while the outer plate *b* is exposed only to the atmosphere, and is comparatively cool. Steam is formed rapidly on the inner plate, consequently there must be a lively circulation in the space between them; but the currents move in opposite directions and interfere to a serious extent. By introducing the baffle plate *c*, the space is divided into two channels, and interference is thus prevented. The currents will move with greater rapidity than before, and the efficiency of the heating surface will be increased.

Baffle plates are applied in many other ways for the purpose of directing circulation currents, and are also used to restrain or confine the water at points where it boils too violently.

1625. Return pipes are tubes which serve to convey the water from the upper part of the boiler to the lower part. They are generally made of large diameter, and are placed so that they will not receive very much heat; sometimes they are located outside the walls of the combustion chamber, and are used principally upon water-tube boilers. The mode of employing them is shown in Fig. 644, in which tubes *e* are the return pipes.

TRANSMISSION OF HEAT.

1626. The rate of transmission through the heating surface of a boiler is always proportional to the difference in temperature of the water and of the hot gases; this rate is also affected by variations in thickness of the metal, and by the form, character, cleanness, and relative position of the various parts of the heating surface. The action of boilers is exactly the same in principle as that of radiators, being merely reversed in operation, and it is affected by similar conditions, in the same manner and degree.

In a radiator, the thickness of the metal is of small importance, mainly because the temperatures are low; but in a boiler, where the parts are exposed to intense heat, it is important that the metal should be as thin as practicable. If the metal is thick, one surface is likely to be much hotter than the other, and the inequality of the expansion causes strains which tend to bulge or crack the plates. In a very thick plate, the surface which is exposed to the hot fire is likely to be overheated and burned, while the surface next to the water remains uninjured, and the plate thus becomes rapidly weakened. A thin steel tube, when full of water, may be exposed to the fiercest fire without injury.

It has been previously shown, in Arts. **1531** to **1533**, that air and other gases can not absorb heat from one side of a metal plate as rapidly as hot water or steam will impart it to the opposite surface. The reverse of this fact is also true, that hot gases can not impart heat to one side of a boiler plate as rapidly as water will absorb it from the opposite side. Therefore, it is an advantage to have the surfaces which are exposed to the hot gases larger in area than those in contact with the water. This is accomplished in "water-tube" boilers by putting the water inside the tubes, and exposing the outer and larger surfaces of the tubes to the fire.

Extended surfaces have been used in boilers to some extent, but while they sometimes afford a gain in efficiency, the advantage is usually overbalanced by the difficulty of keeping them clean and in good order.

1627. Direction of Flow of Gases.—The efficiency of a boiler tube is considerably affected by the manner in which the hot gases pass over its surface. If they flow in a direction parallel with its length, much less heat will be transmitted through it than if they impinge upon it at right angles or flow crosswise over it. The latter condition can be secured only in those boilers which have the water inside of the tubes.

The movements of the water and of the hot gases should be in opposite directions, as nearly as practicable, in order that the coolest part of the water may be exposed to the coolest gases, and that, as its temperature rises, it may be acted upon by successively hotter gases. The greatest practicable difference of temperatures is thus maintained throughout the whole passage of the gases through the boiler; consequently, the maximum amount of heat will be transmitted to the water. If the reverse arrangement were employed, the difference of temperature would be greater near the fire than it would be elsewhere in the flues, and the total transmission of heat would be considerably less.

1628. Length of Tubes.—When the hot gases are passed through small tubes, as in locomotive and tubular boilers, they are cooled very rapidly, and, if the tube is long, the cooling is likely to be so great that the further end of the tube will be practically useless for making steam. In ordinary practice, a boiler tube 3 inches in diameter should not exceed 12 feet in length, and smaller tubes should be made proportionally shorter. If the gases have been partially cooled by passing over other water-heating surfaces before entering the tubes, the length should be reduced accordingly. The aim should be to have the temperature of the gases at the moment they leave the tubes as near to the temperature of the steam as possible, but not to exceed it by more than 100 degrees.

The length of a boiler tube which contains water, as in water-tube boilers, is limited by the rapidity and abundance of the circulation. Very long or very slender tubes are generally objectionable, because of the difficulty of keeping them properly filled with water.

STAYED SURFACES AND BRACES.

1629. Internal steam pressure tends to distort the shape of any vessel which is not truly *spherical* or *cylindrical* in form, and the tendency is proportional to the extent of the variation of its shape from those forms.

All surfaces, curved or flat, which are exposed to steam pressure must be stayed or braced whenever the shape is such that the internal space of the boiler would be increased by bulging or otherwise distorting the plates forming these surfaces.

A hollow sphere can not be distorted by internal pressure, because the volume of the internal space could not be increased thereby. The same is true of a cylinder, except as to the flat end surfaces.

Flat surfaces are more liable to distortion by steam pressure than any others, and they must be carefully supported by stays or braces. These must be attached to the plates at short distances apart, the proper distance depending upon the thickness of the plate and the maximum pressure to be carried in the boiler.

1630. The devices generally used for this purpose are shown in Figs. 628 to 632.

When the plates requiring stays are comparatively near together, they are tied one to the other by means of **staybolts,** such as shown in Fig. 628. The bolt is threaded its entire length, and after it is screwed into place, the ends are riveted over slightly. This heading-over must be comparatively small in extent, otherwise the screw threads may be stripped in the process, and the holding power of the stay thus be nearly destroyed. Staybolts may be used with plates which are either parallel or divergent, provided the angle of the bolt with either plate be not less than about 75°.

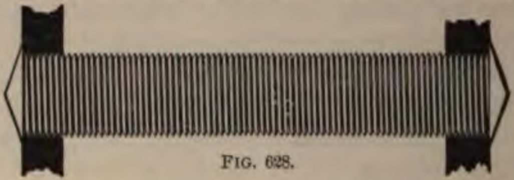

FIG. 628.

1631. The flat ends of ordinary cylindrical boiler shells are usually stayed by means of **stayrods,** which pass through both heads. The most approved mode of fastening these long stays is shown in Fig. 629. The hole is made large enough to pass the body of

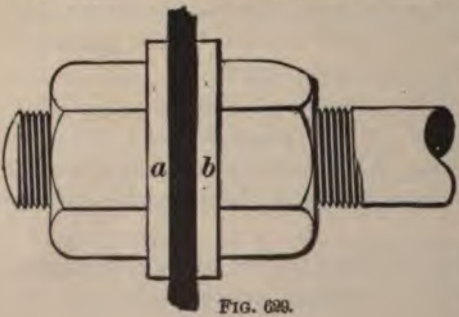

FIG. 629.

the bolt, and the plate is gripped between the nuts, as shown. The washers *a*, *b* serve to make a steam-tight joint, and also to stiffen the plate around the hole. These through stayrods are not suitable for boiler shells having a considerable length, because of the difference in expansion between them and the shell.

1632. Fig. 630 shows a **diagonal stay.** This is made with a T head *A* and a strap end *B*, both of which are secured to the plates by rivets.

All stayrods ought to have at least 25 per cent. more metal in them than is required for strength and security, in order that they may not become weakened to a dangerous degree by corrosion, before the other parts of the boiler are worn out by service. The combined area of the rivets at either end of a stay should fully equal the area of the rod when new. The angle of the rod with the shell should never exceed 30°, and should be as much less as possible.

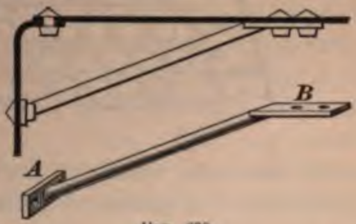

FIG. 630.

1633. Fig. 631 shows a **gusset stay.** This consists of a flat plate, or web, *A* which is connected to the head and shell by double angle iron clips *B*. These clips serve to stiffen the plates to which they are attached, and the number of stays required is thus reduced.

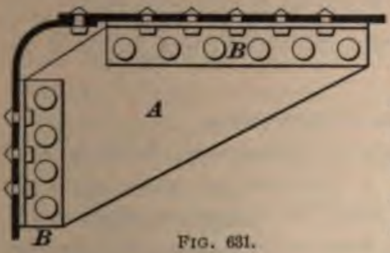

FIG. 631.

1634. Girder stays, or **crown bars,** shown in Fig. 632, are used mainly for supporting the flat sheets *C* which form the tops of fire-boxes, or combustion chambers, commonly called crown sheets. The bars *A* are fastened together in pairs, and are provided with feet which bear firmly upon the edges of the side sheets *B*, *B*. The short, vertical staybolts are riveted to the crown sheet and are provided at their upper ends with large **T** heads, which hook over the edges of the bars as shown. The bars stand clear of the sheet about ¾ of an inch or more, so that the water may circulate freely between them, this distance being maintained by means of washers around each staybolt.

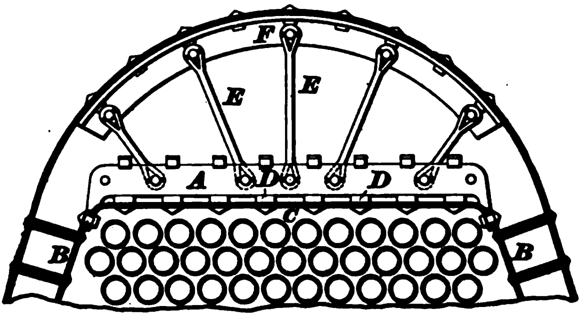

FIG. 682.

1635. To provide additional strength, an angle iron *F* is sometimes riveted to the shell. The crown bar and angle iron are then connected by **sling stays** *E*, *E*. Many makers, however, condemn this construction and depend upon the girders, or crown bars, alone. The crown bars are bolted together in pairs, being held apart by the rivets, and held there by the sling stay pins and the **T** heads of the rivets.

EXTERNAL PRESSURE.

1636. When a large tube or cylindrical chamber, such as a circular fire-box, etc., is exposed to heavy pressure upon its exterior surface, it must be supported against collapse by means of stays. So long as the walls of the chamber remain truly circular and of equal strength throughout, and the exterior pressure is uniform at all points, no collapse will occur. But these conditions rarely occur in practice, and when the pressure is high it is necessary to provide stays in order to secure safety.

Wrought-iron tubes, 8 inches or less in diameter, are abundantly strong to resist external pressure, but internal fire-boxes, smoke chambers, etc., must be stayed. This is usually done by means of staybolts, as shown in Fig. 639. In this case, the smokebox *I* is made conical, and is thereby much stiffer than a cylindrical chamber would be. Otherwise it would require to be stayed like the fire-box.

DEFECTS OF STAYED SURFACES.

1637. Stayed surfaces should be avoided whenever practicable, because the bolts and rods are liable to become weakened by corrosion, and it is impossible in many cases to inspect them. The nature of the construction is such that, if one stay gives way, the strain is instantly increased upon the adjoining ones. Unless these are abundantly strong, they will snap one after another, until the structure is ripped apart and destroyed. Thus, when the crown sheet of a fire-box has been overheated and the heads of the stays burned, if one stay breaks off, the others are apt to follow in quick succession, and the sheet will be blown down with disastrous consequences.

CONSTRUCTION OF BOILERS.

1638. The proper construction of steam boilers is an art which requires a large amount of special knowledge. The principles which govern it, and also the necessary data, have already been given. The following general notes, however, should be carefully considered:

The weakest part of a boiler shell is always in the seams or joints. A **single lap seam** (Fig. 633) is from 60 to 66 per cent. as strong as the original plate, and a **double-riveted lap seam** (Fig. 634) is from 70 to 77 per cent. as strong as the plate. No form of riveted joint is as strong as the

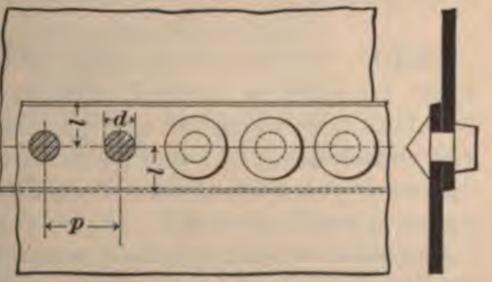

FIG. 633.

original plate. The strength of a joint is only equal to the smaller of these two values, namely, the shearing strength of the rivets which bear the strain, and the tensile strength of that part of *one* plate which remains between the rivet holes.

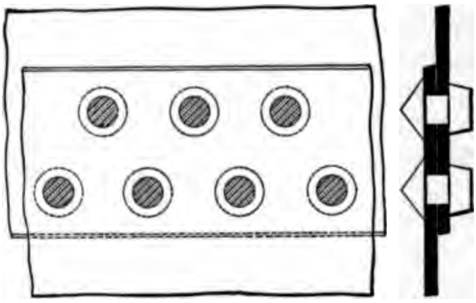

FIG. 684.

The longitudinal seams of boiler shells are usually double-riveted, in order to secure as strong a joint as practicable. The strains which tend to pull these joints apart are just twice as great as those in an equal length of circumferential, or girth, seam.

The riveted joints of boiler shells should not be exposed to the direct action of the fire, if possible to avoid it, because there is so much extra metal in them that they are very likely to be overheated and seriously weakened. The longitudinal seams should be located above the water-line.

All boiler tubes of steel or wrought iron should not be screwed into the tube plates, but should be secured in place by the process known as "expanding." This rule applies to shell boilers and to water-tube boilers of all kinds, including the low-pressure varieties designed especially for steam heating. Threaded tube ends should not be permitted in any form of boiler where they will be exposed to the action of hot gases or fire.

1639. All varieties of boilers should be provided with ample facilities for internal inspection and cleaning. All chambers large enough to admit a man should be provided with **manholes,** and other parts should have **handholes** located at such points that the condition of the plates and stays can readily be seen.

The plate which contains a manhole is seriously weakened by the removal of the metal, and must be reinforced all around the hole by a strong ring of wrought iron. Otherwise the plate is liable to tear from the hole outwards. A good construction of manhole and cover is

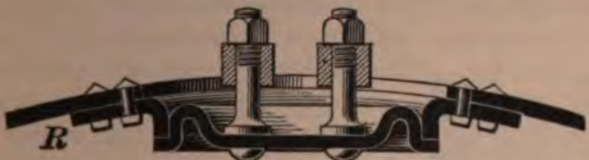

FIG. 635.

shown in Fig. 635. The reenforce ring and cover are made of wrought iron or steel plate. The joint is made steam-tight with ordinary thin gaskets or other packing.

Handholes are usually so small that no reenforce ring is required to strengthen the plate.

DESCRIPTION OF BOILERS.

1640. Boilers containing tubes are divided into two main classes. Those which have the hot gases passing through the tubes are called **fire-tube boilers,** while those which have water upon the inside of the tubes and hot gases upon the outside are called **water-tube boilers,**

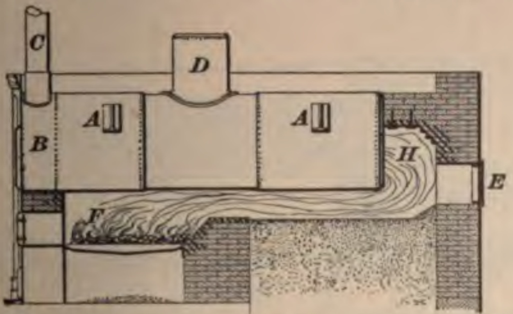

FIG. 636.

The former class is illustrated in Figs. 636 to 641, and the latter class in Figs. 642 to 644. There are a great many varieties of water-tube boilers, but only a few representative forms can be shown here.

1641. The **return tubular boiler** is shown in Figs. 636 and 637. It is so called because the hot gases from the fire *F* pass along under the shell of the boiler and ***return*** at *H* through the tubes to the smokebox *B*; the gases then flow into the smokestack *C*. The boiler is supported upon the side walls by means of angle brackets *A*. These should carry the entire weight of the boiler. The tubes can be got at for cleaning by opening a door in front of *B*, and the soot and ashes can be scraped out through the door *E*. The boiler is usually provided with a dome *D*, though this is sometimes omitted.

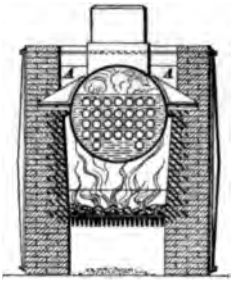

FIG. 637.

1642. The **locomotive boiler** is shown in Fig. 638. The fire-box *F* is internal, and is practically rectangular in form. The hot gases are conveyed to the smokebox *B* in a direct course by the tubes *T*. The tubes are made small in diameter and as numerous as possible, so as to secure a large amount of heating surface. The largest part of the total evaporation, however, takes place upon the sides and top of the fire-box. The cylindrical shell is supported by a brick pier *G* and a cast-iron cradle *E*. A damper is shown in the smokestack at *C*. The steam dome *H* is furnished with a steam-pipe connection *K* and a handhole *L*. A water leg *A* composed of flat plates which are tied together by stay-

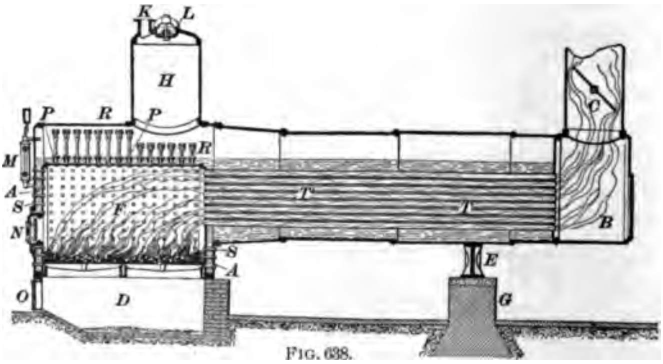

FIG. 638.

bolts *S* surrounds the fire. Fuel is fed to the furnace through the fire door *N*, and the ashpit *D* is cleaned out through the door *O*. A water column surmounted by a steam gauge is connected to the front of the boiler as shown at *M*. The crown sheet is tied to the outer shell *R* by sling stays *P*, in a manner similar to Fig. 632.

1643. The **vertical tubular boiler** is shown in Fig. 639. The water-line *V* is maintained above the level of the upper ends of the tubes *t*, so that they can not, at any time, become overheated. The smokebox *I* is much less liable to damage, although the greater part of its surface is covered only by steam.

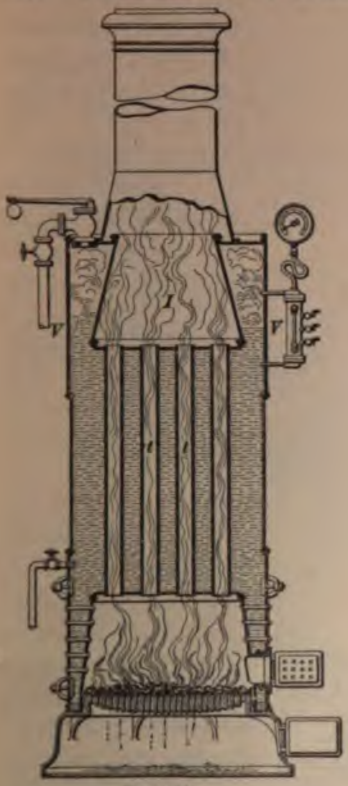

FIG. 639.

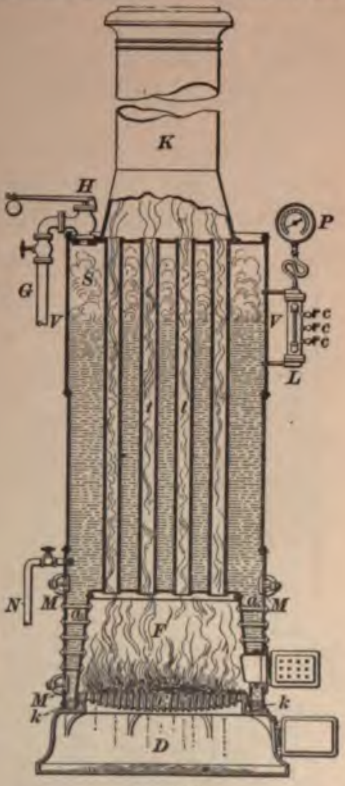

FIG. 640.

In some cheap forms of vertical boilers, the tubes *t* extend up through the steam space *S*, to the top of the shell, as shown in Fig. 640. The upper ends of the tubes are thus uncovered by water, and, the metal being very thin, they are apt to be damaged by overheating. This defect becomes a dangerous one if the boiler is worked hard. In the vertical boiler shown, the grate bars *E* rest upon the top ring of a cast-iron base *D* which forms the ash pit. The crown sheet is kept up high enough to form a good combustion chamber *F*. The boiler is supplied with feed-water through a feed-pipe *N*, and the steam leaves it through a steam pipe *G* which has a lever safety valve *H* attached to its highest point. Handholes *M*, *M* are provided in the shell for access to the inside. Staybolts *a*, *a* are employed to prevent the combustion chamber from collapsing when the boiler is under high pressure. The fire-box and outer shell are securely riveted together at the base, a base ring *k* being used as the distance piece. The steam pressure is indicated by a pressure gauge *P*, and the water-line *V V* is determined either by the gauge glass or the try cocks *c*, *c*, *c*, which are screwed into the water column *L*. The smoke pipe *K* is flared out at its base to take in all the flue tubes.

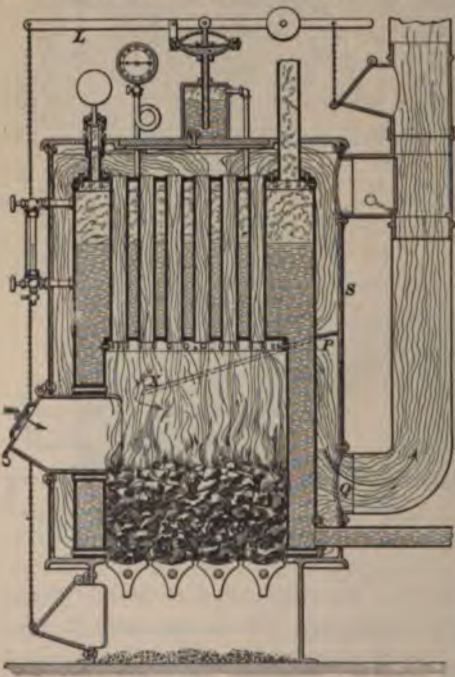

FIG. 641.

Fig. 641 shows a variety of vertical tubular boiler designed for low pressure and small work.

The tubes are short, and the fire-box is very large in proportion to the size of the shell. The hot gases, after passing through the tubes, are passed downwards over the outer surface of the shell, and are allowed to escape through an outlet *Q* near the bottom. The jacket *S* consists of a metal shell, which is lined with a non-conducting and refractory material. An inclined partition *P* extends around the boiler to the point *X*, and compels the gases to pass over nearly the whole outer surface of the boiler shell. The heating surface is thus considerably increased.

1644. The **Babcock & Wilcox boiler** is shown in Fig. 642. It consists mainly of a large number of wrought

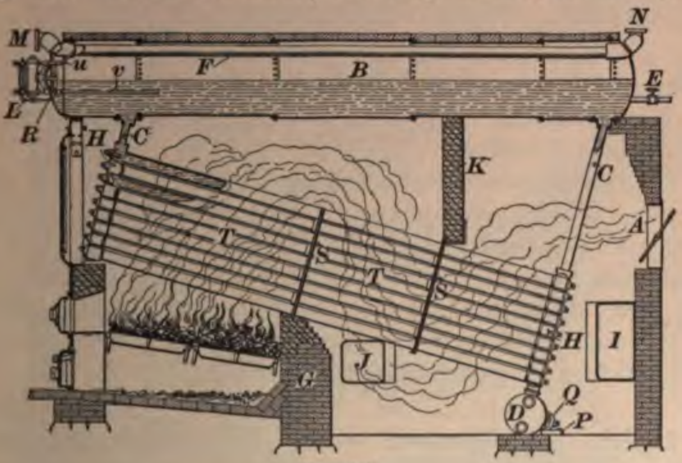

FIG. 642.

iron or steel tubes *T*, which are inclined at an angle of about 15° to the horizontal. The tubes are connected at each end to manifolds, or "headers," *H*, and seven or eight of these vertical rows of tubes are placed side by side. Each header is connected to the steam drum *B* by tubes *C* or *C'*. The water flows towards the front headers and passes up into the steam drum, where the steam bubbles are liberated. The return current flows down through the tubes *C'* into the rear headers. The circulation is very rapid, and the only place where mud or sediment has any chance to lodge is in the mud drum *D*. The hot gases are compelled, by means of firebrick partitions *S* and the suspended wall *K*, to pass over the tubes crosswise three times before they pass out through the opening *A* and into the chimney.

The feed-water is introduced through the feed-pipe *E*. The steam is collected in the dry pipe *F*, which terminates in the nozzles *M* and *N*, to one of which is attached the main steam pipe, and to the other the safety valve.

The pressure gauge, cocks, etc., are attached to the column *L*, which communicates with the interior of the shell by the small pipes *u* and *v*, the former of which extends into the dry pipe, the latter into the water.

A manhole *R* is provided in the front head of the drum, and a sediment pipe *P* and handhole *Q* are connected to the mud drum *D*. Manholes *I*, *J* are provided in the brick setting to facilitate the cleaning of the flues and inspection of the boiler, etc. The bridge wall *G* is built of firebrick close up to the tubes.

The method of supporting the boiler is not shown in the figure. The usual method is to hang the boiler from wrought-iron girders resting on vertical iron columns. The brickwork setting is not depended upon as a means of support. This style of boiler, in common with many others of the water-tube type, requires a brickwork setting to confine the furnace gases to their proper field.

1645. The **Stirling boiler** is shown in Fig. 643. Briefly described, it consists of three steam drums *B* and three sets of inclined tubes which connect them to the mud drum *A*. The steam drums are all connected together by steam circulating pipes *C*, *C*, but only the front and middle drums are connected by water circulating pipes. The water flows upwards in the front row of tubes to the front drum, and passes through the lower circulating tubes *C* to the middle drum, from which it descends through the middle row of tubes to the mud drum, thus forming a continuous circuit. The feed-water is delivered into the rear upper drum and flows slowly downwards through the rear set of tubes to the mud drum, where it enters the main circulation. By this device of moving the feed-water slowly downwards as it is heated, the impurities and sediment are precipitated into the mud drum, from which they are easily removed by the pipe *N*. The combustion chamber is partly covered by a firebrick arch *D*, which becomes incandescent

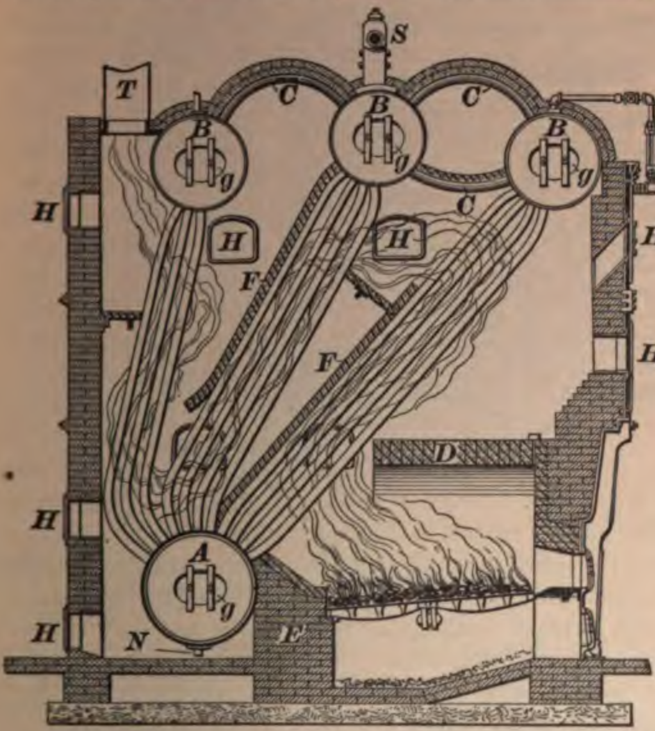

FIG. 643.

and enables a high temperature of combustion to be maintained in the furnace. The steam drums are supported upon iron girders and columns, independent of the brickwork, so that the boiler can not be damaged by the distortion of the enclosing walls. The rear grate bars rest upon a brick bridge wall *E*. Manholes *H*, *H*, etc., are built in the brick walls to provide access to the flues. Firebrick partitions *F*, *F* compel the hot gases to flow between the pipes, as shown, before they enter the chimney *T*. Steam is taken from the boiler by the pipe *S*, and the water-line is shown by a water column *L*. Manholes are placed in the heads of the drums at *g*, *g*, etc.

1646. Fig. 644 shows a variety of **box coil boiler** which is designed especially for heating purposes. It consists of two mud drums and two water drums *b*, to which are connected a series of inclined zigzag tubes *d*. Each alternate tube is connected to the drums on the opposite side of the boiler. The water flows upwards from the mud drums through the inclined tubes to the water drums, and descends through the large vertical return pipes *e*. Steam collects in the steam drum *c*. The furnace may be placed either under the boiler or at one end, the gases in the latter case moving horizontally, thus enabling the boiler to be used in places having low ceilings. The boiler is enclosed in plain rectangular brick walls, and may be set in almost any position desired. The arrangement of the heating surfaces is such that steam is generated very rapidly.

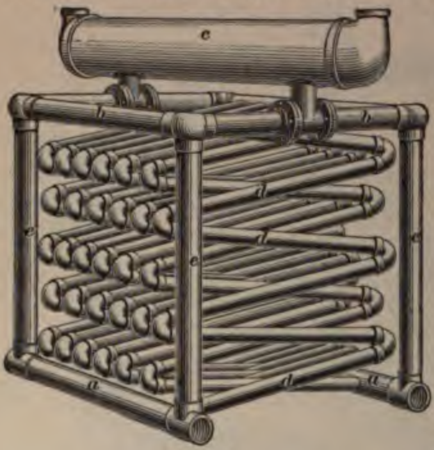

FIG. 644.

SECTIONAL BOILERS.

1647. This term is applied to a class of boilers which are composed of a number of independent sections connected in such a manner that the group will operate as one structure. Thus, a boiler may be made of large or small capacity, as desired, by varying the number of sections. This mode of construction is employed principally for low-pressure cast-iron boilers, but there are also a few varieties of water-tube boilers to which the term "sectional" may be correctly applied.

1648. Figs. 645 and 646 show the construction of a well-known **cast-iron sectional boiler** suited for domestic heating. The water is contained in cast-iron chambers, one of which is shown in detail in Fig. 646; the water passes from one section to another through the openings *m*. The several sections are bound together by bolts which pass up through these openings, and the joints are made water and steam tight by means of a suitable packing. The inner edge of each ring is corrugated, as shown at *a*, so as

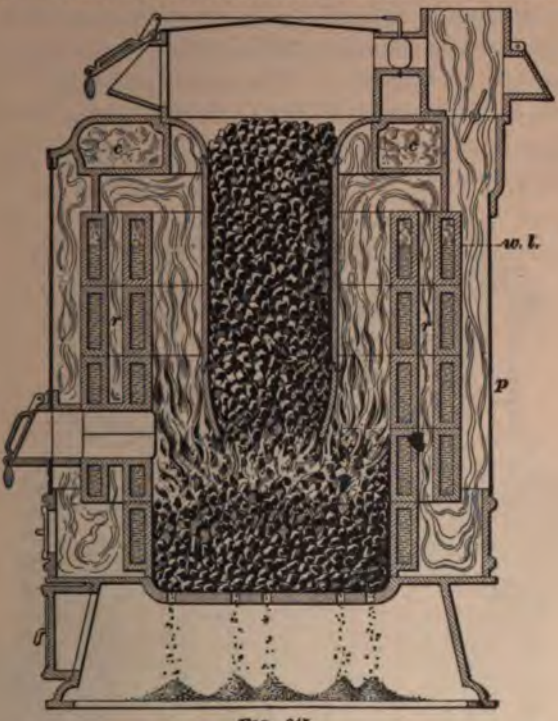

FIG. 645.

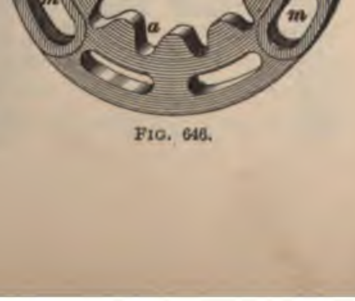

FIG. 646.

to secure a large amount of heating surface. The water-level is maintained at the line *w l*. The top section *c* serves as a steam drum. The hot gases pass upwards between the inner faces of the sections and the magazine *d*, and descend through the passages *r*. They then pass upwards again between the outer faces of the sections and the jacket *p*.

1649. Another type of cast-iron sectional boiler, for low pressures only, is shown in Figs. 647 and 648. In this case there is no direct connection between the different sections, each one being independently connected, by suitable nipples, to the steam drum *c*, and to the feed-pipes, or mud drums, *b* and *d*. A pair of sections are shown in detail in Fig. 648. The water circulates freely in each section, entering the water legs *a*, passing up the inclined tubes *k*, and descending through the channel in the outer rim of the section. The hot gases impinge upon the tubes *k* and pass between

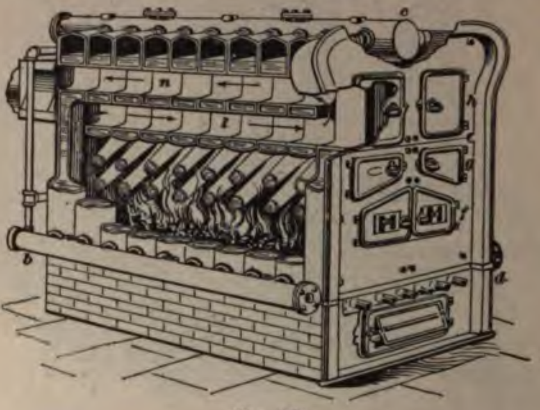

FIG. 647.

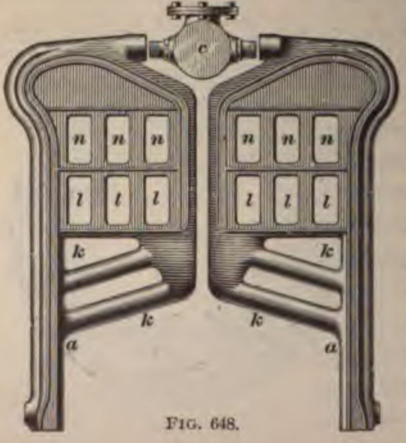

FIG. 648.

them to the rear-end section. They then pass forwards to the front through the passages *l*, and return to the rear through the upper passages *n*. Fuel is supplied to the furnace through the doors *f*. The water-tube, or fire, surface is cleaned through doors *g*, and the flues *n* and *l* are cleaned out through the doors *h*. An advantageous feature of this construction is the fact that each section is practically an independent boiler, and is provided with a good circulation.

1650. Fig. 649 shows part of a **cast-iron drop tube boiler** for low pressures. It consists of a steam chamber *a*, from which a number of drop tubes *b* and *d* are suspended. The long tubes stand closely together, thus enclosing a fire space and a combustion chamber. The short tubes hang down over the fire and are separated sufficiently to allow the

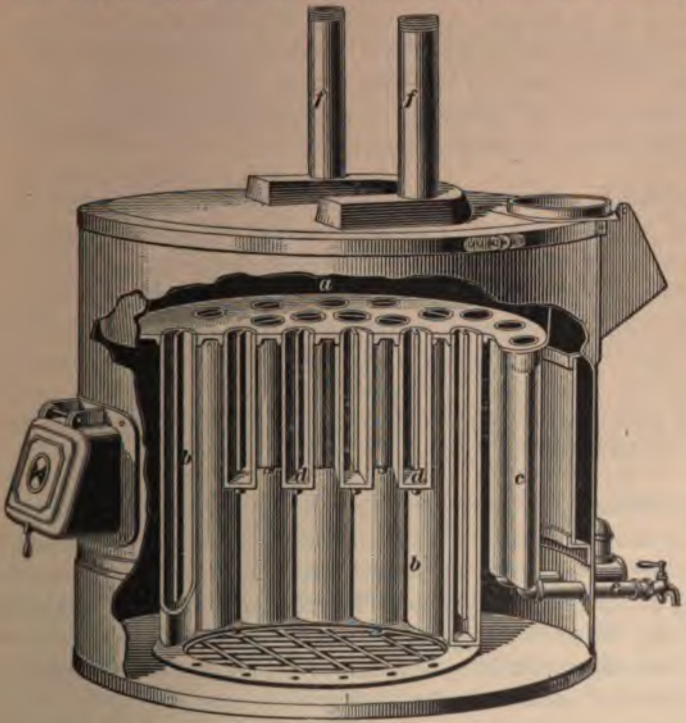

FIG. 649.

hot gases to circulate freely among them. Feed-water is introduced through one of the rear drop tubes *c*, and the pipe *e* is used as a blow-off, but, of course, it can not empty the tubes. Steam is taken off by the pipes *f*. Each drop tube is provided with a diaphragm to aid circulation, as shown in detail in Fig. 626.

HORSEPOWER.

1651. This term is used for two purposes which are widely different—first, to indicate the lifting power of a *motor* of any kind, either animal or mechanical, and second, to indicate the ability of a *boiler* to absorb and transmit heat. The first use is correct and proper, but the latter is based upon an arbitrary assumption which has no definite relation to a motor horsepower.

1652. Horsepower of an Engine.—The **power** of any variety of motor is measured by its ability to lift weights through a vertical distance of one foot in one minute of time. The actual weight, time, and distance may vary indefinitely, but the product of the weight and distance divided by the time is the thing to be considered. Thus, the power required to lift one pound 1,000 feet in one minute is exactly the same as that required to lift 500 pounds through 6 inches in fifteen seconds.

1653. The unit used in all measurements of work is the **foot-pound.** This is equal to the work performed in lifting a weight of one pound one foot high, or in overcoming a resistance of one pound through a distance of one foot in any direction, the time being left out of consideration. A **horsepower** is equivalent to 33,000 foot-pounds of work performed in one minute of time.

1654. The power of an engine is computed by the following

Rule.—*Multiply together the area of the piston, in inches; the average pressure of the steam in the cylinder above the* *back pressure, in pounds; the distance traveled by the piston in making one complete revolution, in feet; and the number of revolutions made per minute; divide this product by 33,000. The result is the horsepower.*

EXAMPLE.—How much power is exerted by an elevator engine having two cylinders, 6 inches diameter and 9 inches stroke, running at 200 revolutions per minute, the average pressure in the cylinder in excess of the back pressure being 45 pounds per square inch?

SOLUTION.—Area of pistons, $2 \times 28.27 = 56.54$ sq. in. Travel of each piston in one revolution, 9 in. $\times 2 = 1.5$ ft.

$$\frac{56.54 \times 45 \times 1.5 \times 200}{33,000} = 23.13 \text{ H. P.} \quad \text{Ans.}$$

The actual average pressure in the cylinder can be found only by means of the steam-engine "indicator," but for ordinary purposes it may be safely assumed to be two-thirds of the pressure shown by the steam gauge, the gauge being attached near the engine.

The quantity of steam required for engines of ordinary construction, without automatic "cut-off" valves or condensing apparatus, should be estimated at 30 pounds per hour per horsepower, the steam being at a pressure of 70 pounds by the gauge. If a lighter pressure is used, the quantity must be correspondingly increased.

1655. Horsepower of a Boiler.—This phrase was originally intended to mean that a boiler having a certain stated "horsepower" would furnish all the steam which was required to develop that amount of power in an ordinary engine, the standard engine at that time being a plain slide valve engine, using about 30 pounds of steam at 70 pounds gauge pressure per horsepower per hour. Subsequent improvements in engines, however, have greatly reduced the amount of steam required, being as low as 13 pounds in some of the best engines. The term has thus lost its original meaning. To remedy this defect, the American Society of Mechanical Engineers has adopted a new definition, which is that *one boiler horsepower equals 33,330 B. T. U. per hour absorbed and transmitted from the fuel to the steam or water.*

This quantity of heat is about 13 times as great as that represented by a motor horsepower for the same time, as shown by the following figures:

$$1 \text{ Motor H. P. per hour} = \frac{33{,}000 \times 60}{778} = 2{,}545 \text{ B. T. U.}$$

$$1 \text{ Boiler H. P. per hour} \ldots\ldots\ldots\ldots = 33{,}330 \text{ B. T. U.}$$

The horsepower of a boiler is the measure of its performance under any certain given conditions, and *does not indicate its capabilities* when employed under other conditions. Thus, a boiler engaged in heating water in an open system, with a slow fire, would develop a much smaller horsepower than it would if employed in making high-pressure steam with a forced blast and intense fire.

1656. Boilers are also rated by their ability to evaporate water from and at a temperature of 212°, 30 pounds per hour being reckoned as one horsepower. This method, however, is merely an indirect way of arriving at the number of heat units transmitted through the boiler, and has no particular advantage. The method given, of rating by the number of heat units actually transmitted per hour, enables all varieties of steam and hot-water boilers and hot-air furnaces to be compared directly, without further computation or trouble.

HEATING SURFACE.

1657. The amount of heating surface required per horsepower varies greatly in different kinds of boilers. The following table shows the amount generally allowed:

TABLE 69.

	Square Feet.
Cylinder	6 to 10
Return tubular	14 to 18
Vertical tubular	15 to 20
Water-tube	10 to 12
Locomotive	12 to 16
Cast-iron sectional	10 to 14

In practice, the rate of heat transmission per square foot of heating surface varies from 800 B. T. U., or more, per hour, in cast-iron sectional boilers for domestic heating, up to 15,000 B. T. U. per hour in the high-pressure water-tube boilers used in torpedo boats.

The actual heating surface of a boiler includes all parts which have water upon one side of the metal, and *gas at a higher temperature than the water* upon the other. Surfaces which are covered only with steam have very little value as heating surfaces.

GRATE SURFACE.

1658. The area of grate surface required in any given case depends almost entirely upon the type of boiler employed and the rate of combustion. Assuming that the total heating surface is ample for the work to be done, the proper area of the grates, in square feet, may be computed by multiplying the horsepower of the boiler by certain factors, which are as follows:

Cylinder boilers	.60
Flue	.45
Return tubular	.50
Water-tube	.30
Vertical	.65
Locomotive (stationary)	.40

These factors are suitable for a rate of combustion of about twelve pounds of coal per square foot per hour, and should be modified for other rates.

Practice has shown that, with this rate of combustion, the ratio of heating surface to grate surface in a return tubular boiler should be about 45 to 1 with bituminous coal, and 36 to 1 with anthracite.

PRIMING AND FOAMING.

1659. In operating steam boilers, it is sometimes found that very wet steam is formed. This consists of normal steam which is loaded with water in the shape of minute bubbles or vesicles, that is, in the condition of spray or mist.

This spray does not readily settle so long as there is any perceptible current or motion in the steam, and it is likely to remain in suspension until the steam is lowered in pressure, or partially condensed.

1660. Priming is caused by violent boiling, which projects the water into the steam space in a shower of drops. This is usually due to the insufficiency of the disengaging surface where the steam parts from the water, but it may also be caused, in cases where this surface is ample, by concentrating the rising currents of steam or steam-laden water too much at one point in the steam drum. In such a case the trouble may be mitigated or cured by checking the velocity of the currents and dispersing them over a larger area by the judicious use of baffle plates.

It is necessary that the surface of the water in the steam drum should have sufficient area to permit the steam to rise from it *at a velocity not exceeding 2½ feet per second.* If this velocity is exceeded, the steam will carry over more or less of the water with it in the condition of fine spray.

Boilers which have the fault of priming, consume water very rapidly and *apparently* have great evaporative power. The appearance, however, is very deceptive, because the steam produced is really a mixture of steam and hot water. The real evaporative power, measured by the amount of heat carried by the steam, will usually be found to be quite small.

As the maximum theoretical evaporative power of one pound of coal is about 13 pounds of water, it follows that boilers which appear to consume 15 to 20 pounds of feed-water per pound of fuel, if tolerated at all, should be considered merely as hot-water apparatus.

1661. Foaming occurs when the rising steam bubbles do not break on coming to the surface of the water, but retain their vesicular form and unite into masses of foam. It is always due to impurities in the water, and can be cured only by using proper purifying apparatus or by securing fresh, clean water.

Foaming should not be confused with *priming*. A boiler having no tendency to prime may foam badly if supplied with impure water; but, if it does prime, the foaming will be greatly aggravated.

Foaming is very dangerous. The steam is then loaded with such quantities of water that the engines, etc., are liable to be damaged, and the water is removed from the boiler so rapidly that, unless it be closely watched, the heating surfaces will become uncovered and burned.

INCRUSTATION AND SEDIMENT.

1662. Natural waters, such as usually supplied to steam boilers, generally contain a greater or less amount of carbonate or sulphate of lime, and also some organic matter. The amount contained in a single gallon is trifling, but the amount left behind in a week by the evaporation of the water is often a serious matter. The substances named would cause very little trouble if it were not for the fact that, while they are soluble in cold water, they are also quite insoluble in hot water. As the water nears the temperature of 200°, these substances begin to separate and settle to the bottom, and they will be wholly precipitated when the temperature reaches 290°.

The carbonate of lime is thrown down as a fine soft mud, which can be easily removed by washing or blowing out. If, however, it comes in contact with tallow or other animal oil, it will form a spongy granular crust which adheres strongly to the plates, and is troublesome to remove. Very many cases of overheated and burned plates result directly from allowing animal fats to enter the boiler in some way.

The sulphate of lime forms a hard crystalline scale which adheres to the plates and other heating surfaces so firmly that it can be removed only by scrapers or by hammer and chisel. The sulphate and chloride of magnesia are occasionally found among the impurities of feed-water, and they behave like the sulphate of lime, and may be got rid of by the same means.

1663. The **effect of incrustation** is to retard the transmission of heat to the water, and when the scale is thick the heating surfaces are very liable to be burned. A scale $\frac{1}{16}$ inch in thickness will cause a loss in fuel of about 13 per cent.; $\frac{1}{4}$ inch thick, 35 per cent., and $\frac{1}{2}$ inch thick, from 50 to 60 per cent. Incrustation has in many cases led to trouble and disaster by choking the feed-pipe or the blow-off pipe, and by clogging the connections to the glass water gauge, causing it to give false indications. A coat of scale may also conceal defective rivet heads or a dangerously corroded piece of plate, which would otherwise be noticed.

1664. When impure water is used in steam boilers, a **mud drum** should always be provided to receive the precipitated matter and sediment, and hold it until it can be removed by washing or blowing out. These matters will settle only where the water is quiet; therefore, the mud drum must be located apart from the main line of circulation, but still in some place where the sediment will naturally gravitate into it.

1665. Prevention of Scale.—The formation of scale may best be prevented by heating the water to the boiling point and precipitating the scale-forming impurities before the water is allowed to enter the boiler. Some boilers are specially designed to arrest these precipitates and remove them from the main circulation, notably the kinds shown in Figs. 642 and 643. Such boilers do not require the assistance of a feed-water purifier, except in cases where the water is extremely bad.

Muddy water should be filtered before it is allowed to pass into either a purifier or a boiler, in order to remove the mud and organic matter.

The various compounds of lime or magnesia which form scale may be decomposed or changed to harmless forms by adding certain chemicals to the feed-water. When the principal impurity in the water is sulphate of lime, it may be reduced to the form of a carbonate by dosing the water with soda ash or carbonate of soda, thus forming a soft muddy deposit which is easily blown out. This must not be used to excess, however, because it tends to make the water soapy, and thus cause foaming.

When carbonate of lime is present in such quantities that it can not be properly removed by blowing off, sal-ammoniac or caustic lime may be added to the water.

Kerosene oil is very useful for preventing and also for loosening scale. One quart per day is said to be sufficient to keep a 100 H. P. boiler clean, even when using very impure water. *Crude* petroleum is corrosive, and should not be employed for this purpose.

Organic matter tends to harden the scale, and also to corrode the metal composing the boiler. Therefore, all barks, woods, and extracts, molasses, vinegar, etc., should be excluded. While these substances contain elements which soften some kinds of scale, their corrosive action far outweighs their value as a scale preventive.

1666. Feed-Water Purifier.—The purifier shown in Fig. 650 consists of a series of long, shallow troughs or

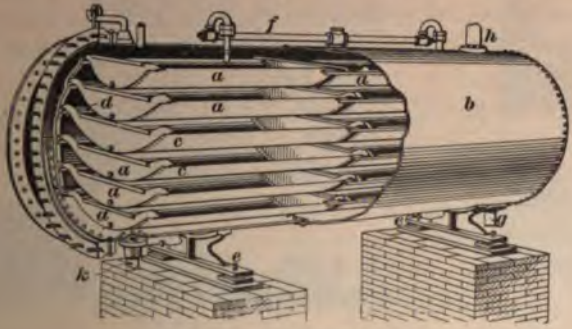

FIG. 650.

pans *a*, which are set one above another and enclosed within the shell *b*, as shown. The pans are quite shallow, and are rounded on the bottom. They are supported at each end by lugs *c* which rest upon angle-iron guides *d* riveted to the shell. Each pan is carefully constructed, so that when it is in its proper place its edges will be exactly level and horizontal, and the shell is also provided with leveling screws *e*, by which it may be adjusted to a perfect level. The feed-water is introduced through the pipe *f*, and delivered at the center of each of the top pans. When a pan becomes full, the water overflows uniformly along both edges and trickles down in a thin film over the rounded bottom, and drops off along the center line into the next pan below. Thus, the water passes successively over each pan in the series, and finally drops into the bottom of the shell, from which it passes out through the pipe *g* to the boiler.

The shell is filled with steam, either live or exhaust, and as the water trickles over the bottom surfaces of the pans it is quickly heated. The scale-forming compounds of lime or magnesia which are dissolved in the water are precipitated as it becomes hot and form a coating upon the surface of the pans. The soft carbonates form a kind of mud which collects in the pans and gradually fills them. These incrustations and deposits, however, do not affect the operation of the purifier, because the water always flows upon the outside of them, and is thus in direct contact with the steam. The pans need to be removed and cleaned only when they become full.

When the purifier is used with live steam, it is set at such an elevation that the water will run to the boiler by the force of gravity alone. Steam is admitted through the pipe *h*, and a blow-off pipe is connected at *k*. When used with exhaust steam, the water is allowed to accumulate in the shell to the depth of a few inches, and the feed-pump is connected to the pipe *g*. The admission of fresh water to the heater is controlled by a float resting on the water at the bottom, and a ball-cock on the pipe *f*. The exhaust steam must be passed through an oil catcher, or separator, before entering the shell, so as to prevent any oil or grease from being carried from the engines over into the boilers. Part of the steam will be condensed, and will thus increase the volume of the feed-water. The shell should be well covered with non-conducting material when it is desired to prevent loss of heat.

CORROSION.

1667. When in service, the parts of a boiler which are in contact with water are liable to be slowly oxidized and reduced in thickness. The oxidation may occur uniformly over large surfaces, or, owing to some peculiarity in the metal, it may be confined to a number of small spots, or to streaks.

In cases of uniform corrosion, the plates are eaten away without showing any plain line of division between the sound and damaged parts. The only sure method of detecting the injury is to drill a small hole through the suspected part and measure its thickness.

1668. Pitting, or **honeycombing,** is shown in Fig. 651. The plate is eaten away in cavities or "pits," from $\frac{1}{32}$ to $\frac{1}{8}$ inch deep. The intervening metal is frequently left at its original thickness, as shown in the cross-section.

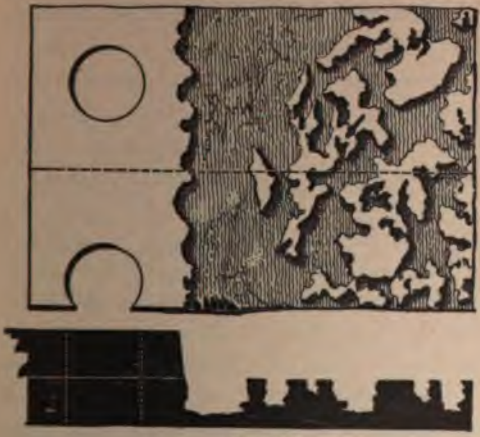

FIG. 651.

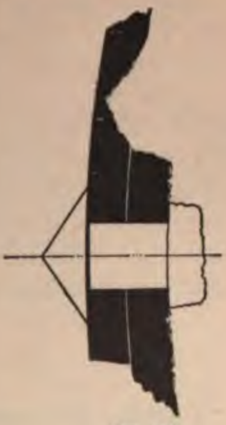

FIG. 652.

Corrosion in narrow streaks is called **grooving.** It is generally caused by the bending action of the plates when under pressure. Thus, the ordinary lap joint of a boiler distorts the shell slightly from a truly cylindrical form, and the steam pressure tends to bend the plates at the joint. This action is liable to start a small crack along the lap, which, being acted upon by the corrosive agents in the water, soon deepens into a groove, as shown in Fig. 652. The mark made along the seam by a sharp calking tool, when used by careless workmen, is almost certain to lead to grooving.

Rivet heads are frequently eaten away by corrosion until their holding power is destroyed. Staybolts and brace rods are particularly liable to corrosion.

Corrosion is generally caused by acids which contaminate the water. All varieties of acids are harmful. In mining regions the waters frequently contain sulphuric acid, and water from small ponds or shallow wells usually contains more or less of tannic, acetic, and other organic acids. The only way of neutralizing acids is to introduce a sufficient amount of alkali, such as soda or potash.

A boiler may be protected from corrosion by putting into the water a few plates of some metal *which will corrode more readily than the iron.* Zinc is found to answer the purpose very well, and as long as a reasonable quantity of it remains in the boiler, the corrosive agents will attack only the zinc, and will leave the iron unharmed. About 1 square inch of zinc plate should be supplied for each 50 pounds of water contained in the boiler when in normal working condition. The best way to prevent corrosion, however, is to purify the water before it enters the boiler.

CLEANING.

1669. In order to secure the greatest efficiency and economy in the working of a boiler, it is necessary that all of the heating surfaces be kept clean, both on the *inside and outside.* The interior should be examined frequently, and no scale or mud permitted to remain. The notion sometimes put forwards, that a thin coating or scale is desirable as a protection against corrosion, is a very expensive fallacy.

The blow-off pipe must be connected to the boiler at a point where it will remove the mud and sediment in an effective manner; otherwise, it will be of little use.

All heating surfaces should be kept clear of deposits of dust or soot, because they obstruct the transmission of heat. If they are burned on in a crust, they should be removed with a scraper. Fire tubes quickly fill up with dust, and must be cleaned with a brush or scraper at short intervals. Water tubes should be brushed and cleaned on the outside, to keep their surfaces in good condition for absorbing heat. Fire-tubes suffer more loss of efficiency by the accumulation of dirt than water tubes, as is clearly shown in Fig. 653. The deposit of dirt in the fire tube not only reduces the amount of effective heating surface, but also reduces the area of the flue, and thus obstructs the draft.

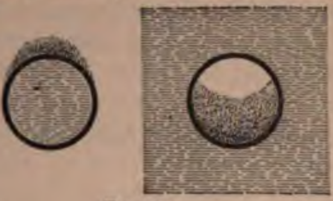
FIG. 653.

BOILER SETTINGS.

1670. The walls which constitute a boiler setting have several duties to perform: *first*, in many cases to sustain the weight of the boiler and maintain it in position; *second*, to confine the fire and properly direct the hot gases; and *third*, to prevent loss of heat as much as possible.

1671. Stays.—Brick walls are always subject to distortion when exposed to heat, and if not carefully confined, will become cracked and bulged so much out of shape that they will not properly support the boiler. Therefore, they must be well bound by means of **buckstays** and **tie-rods,** as in Fig. 637. The tie-rods should pass through from side to side, if practicable, instead of being merely anchored in the brickwork. Such bolts should not be embedded in masonry, if possible to avoid it. A hole should be formed in the brickwork large enough to permit the bolt to pass through freely, so that if it becomes broken or corroded, it may be easily renewed.

1672. Supports.—The best practice is to suspend all large boilers from horizontal wrought-iron girders by adjustable hangers, and to support the girders upon wrought-iron posts which are practically independent of the brick walls. When the shell is supported by brackets, as in Figs. 636 and 637, the brackets should rest upon rollers, so that the boiler may expand and contract freely. The rollers should bear upon stiff iron plates firmly embedded in the brickwork.

1673. Fire Line.—No part of the boiler which is not covered with water at all times should ever be exposed to the hot gases. In other words, the fire line should always be below the *lowest* water-level.

1674. Firebrick Linings.—All parts of the walls which are exposed to fire or hot gases should be faced with firebrick of good quality. The lining should not be less than 4½ inches thick, and should be so laid that it can be easily renewed without destroying the main walls.

1675. Detachment of Walls.—The walls enclosing a boiler must be made independent of all other walls, so that they can expand and contract freely. They must never be bonded into the walls of a building nor into a brick smokestack. A slip, or straight, joint must always be interposed between boiler walls and all other masonry. Similarly, a large, heavy brick smokestack must never be bonded into the walls of a building, because it will inevitably settle more than the building, and will cause extensive cracks.

1676. Covering.—The exposed parts of a boiler should always be covered with some good non-conducting material, to prevent loss of heat. Cylindrical boilers may be arched over with brick if desired. The brick should not touch the shell, but should stand off about one inch. A more convenient and equally good method is to cover the boiler with dry loam to a depth of 4 to 6 inches. This can be readily shoveled away when desired, for inspection and repairs.

1677. Double walls are sometimes made for the purpose of conserving the heat, and the air for combustion is taken in through the space between them. Of course, all the heat thus intercepted, which would otherwise escape, is a real saving, but the gain is comparatively small, and will seldom compensate for the expense, except in the case of large boilers.

1678. Defective Setting.—Return tubular boilers are sometimes set so that the gases, after passing through the tubes, are returned over the top of the shell in contact with the steam space. This construction is bad, and should never be permitted.

1679. Sediment.—Cylindrical boilers which are not provided with good feed-water purifiers should be set on an inclination of about 1 inch in 10 or 12 feet, the end over the fire being highest. The mud and sediment will then gravitate towards the rear end, and the tendency to form scale on the plates over the fire will be reduced.

1680. Cleaning doors should be provided, which will give easy access to all of the heating surfaces of the boiler which are liable to become covered with soot or dust, and to all parts of the flues which may accumulate soot or ashes. If the spent gases are conveyed to the stack through iron pipes, manholes with tight covers should be provided at intervals, so that the entire length of pipes may be easily brushed out.

1681. Clearance.—When setting up a boiler, care should be taken to secure ample room around it for handling the fire tools, cleaning brushes, etc., and to provide a good passageway for a wheelbarrow for removing the scrapings and dirt.

FITTINGS AND APPLIANCES.

1682. The safety devices in common use consist of *safety*, or *relief*, *valves*, *low-water alarms*, and *fusible plugs*.

SAFETY VALVES.

1683. Safety valves are of three kinds, which are respectively known as the *dead-weight*, the *lever*, and the *spring* valve.

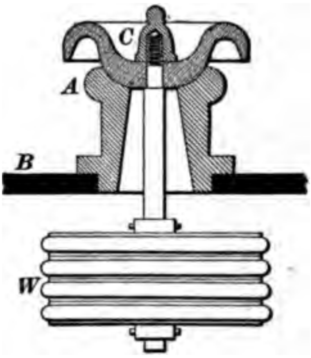

FIG. 654.

1684. The **dead-weight safety valve** is shown in Fig. 654. The valve *C* is seated on the end of a casting *A* attached to the boiler *B*, and is held down by the annular weights *W*. The resistance of this valve to the escape of steam can be altered only by changing the number or size of the weights. Another variety of dead-weight valve is shown in Fig. 641.

1685. The **lever safety valve** is shown in Fig. 655. The steam enters from the boiler at *S* and escapes at *R*.

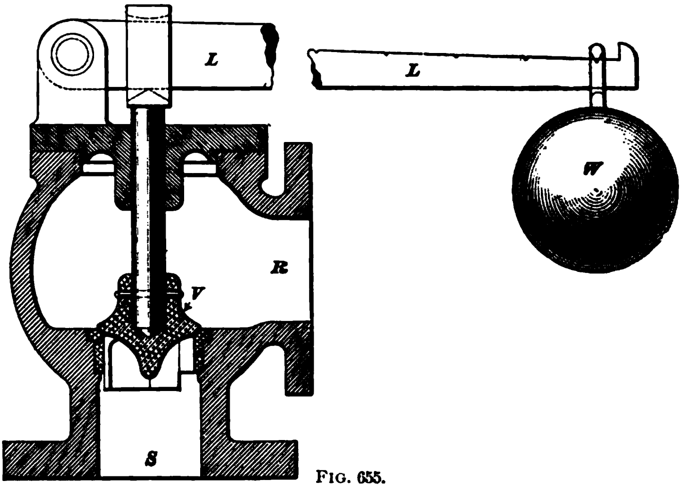

FIG. 655.

The valve *V* is held down on its seat by the stem and lever *L*. The load on the valve can be adjusted by moving the weight *W* along the lever, being greatest when the weight is at the outer end.

1686. The **spring safety valve** is shown in Fig. 656. The valve *V* is held down by means of a strong spiral spring *S* acting on the stem *T*; the pressure of the spring can be altered by adjusting the nuts shown at the top of the casing. The valve shown in this construction is much superior to the forms shown in Figs. 654 and 655. It is annular in form, and bears upon two seats, *M* and *N*, formed in the main casting *A*. The steam in the boiler acts only upon the area between the inner and outer seats, and when the pressure rises high enough to lift the spring, the steam rushes over the outer seat into the air and over the inner seat into the cup, or chamber, *B*. It escapes from this chamber through the small ducts *C*, but not so rapidly as it enters, and, consequently, the pressure in *B* rises. This pressure acts upon the end of the valve stem and tends to lift the valve wide open, thus permitting the excess of steam in the boiler to escape very rapidly. Owing to the abrupt manner in which the valve opens and closes, it is called a "pop" valve.

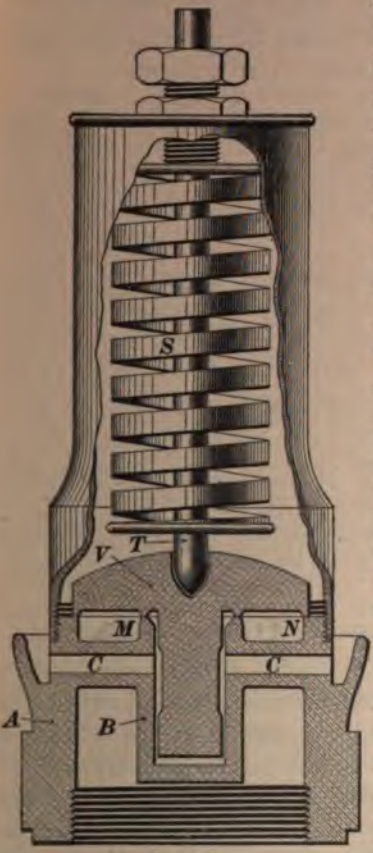

FIG. 656.

Valves constructed in this manner will not permit the pressure in the boiler to rise above that for which the valve is set, but with the forms shown in Figs. 654 and 655, the pressure must rise several pounds above the desired limit before the valves can discharge freely. The pop valve is preferable in all cases. Another reason for preferring the spring valve to all other kinds is the facility with which it can be enclosed in a case and locked up, so as to prevent all changing or tampering by unauthorized persons.

1687. The *area* of a safety valve should be large enough to discharge the steam as rapidly as the boiler can generate it. The size of the valve relative to the size of boiler and the working pressure is prescribed by law in many localities.

A safety valve should be attached to the boiler in the most direct manner. No stop-valve of any description should be permitted between it and the boiler under any circumstances. Safety valves are liable to become corroded and stick fast to their seats; therefore, they should be lifted and blown off every day to make sure that they are in good working order. Many spring safety valves are specially provided with levers for this purpose.

LOW-WATER ALARMS.

1688. These devices are usually constructed so as to sound a whistle or ring an electric bell when the water becomes too low in the boiler for safety. Some forms are also designed to give an alarm when the supply of water becomes excessive. One of this class is shown in Fig. 657. The whistle *a* is operated by a float *b*, which rests upon the water and moves up and down with it as the water-level changes. The stem

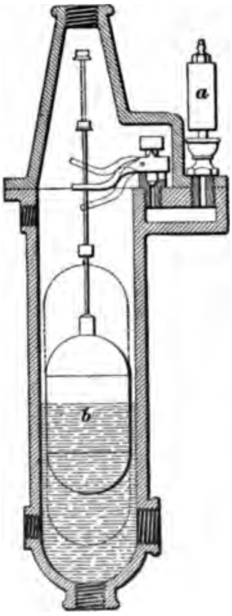

FIG. 657.

of the float passes through an eye in the end of the whistle lever, and is provided with two adjustable collars, as shown. When the water falls to the lowest limit, the float pulls down on the lever and lifts the valve, thus sounding the alarm. When the water rises too high, as it may do if the feeding apparatus is neglected, the float lifts the lever and again blows the whistle. Thus warning is given of either a deficiency or an excess of water.

1689. Another variety is made to operate by virtue of the difference in expansion of two tubes, one of iron and the other of brass. This apparatus is arranged so that it will be full of water when the water-level is at a proper height; it is exposed freely to the air so that the water contained in it may become comparatively cool.

When the water-level falls too low, this water runs back into the boiler and its place is filled by hot steam. The resultant expansion of the metal parts is utilized to open a whistle valve.

In devices of the latter kind, the movement of the valve is usually so small that it is easily clogged with dirt or a flake of scale, etc., and is thus made inoperative. It is, therefore, very unwise to depend upon them alone for safety. Boiler attendants sometimes form the habit of waiting for the alarm whistle before attending to the feed-water; such a habit is extremely dangerous, and should not be tolerated.

1690. **Fusible plugs** are placed in the crown sheets of furnaces as a safeguard against overheating through the water running low. The plug consists of an alloy of tin, lead, and bismuth, which melts at a low temperature. So long as the furnace crown is well covered with water, the plug is kept from melting by the good conductivity of the water, but should the water sink low enough to uncover the top of the plug, it quickly melts and allows the steam and water to rush into the furnace, thus relieving the pressure and extinguishing the fire.

A good form of fusible plug is shown in Fig. 658. The plug *P* is screwed into the crown sheet *Q*, and the fusible cap *R* is laid on top of it and kept in place by the nut *U*. A very thin copper disk *S* is placed over the top of the cap *R* to protect it from any chemical action of the water. The top of the cap extends from 1½ inches to 2 inches above the crown sheet, so that when it melts on account of the water being too low, there will still be enough water left to protect the sheet from burning. In many instances, fusible plugs are required by law.

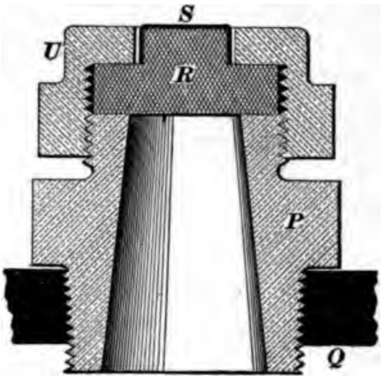

FIG. 658.

DAMPER REGULATORS.

1691. The regulators which are used to control the fire in steam-heating apparatus are essentially different from those used in hot-water and hot-air heating. In the former case, the regulator is actuated by variations in the *pressure* of the steam; but, in the latter cases, the only thing available for regulating purposes is the variation in *temperature* of the heating agent.

The damper regulators used in steam heating are of two kinds, one being operated by a flexible diaphragm and the other by a piston.

1692. A **diaphragm regulator** is shown on top of the boiler in Fig. 641. It consists of two bowl-shaped castings having a flexible diaphragm of rubber clamped between them. The lower bowl is filled with water under full steam pressure, and the upper bowl serves merely as a cover and guide for the stem which is attached to the lever *L*. The motion of the diaphragm is multiplied by the lever, and transmitted to the dampers by the chains, as shown. The weight on the lever tends to depress the diaphragm and open the lower draft door, but when the steam pressure becomes excessive the diaphragm rises, thus closing the lower draft door and opening the upper, or check, damper. The length of the chains must be adjusted so that both dampers may be closed when the lever is in a horizontal position, and there should then be very little slack in the chains. The object of the water chamber to which the regulator is attached is to make sure that the space below the diaphragm is filled with water instead of steam, the heat of live steam being very destructive to rubber. The apparatus may be adjusted to suit the desired steam pressure by shifting the weight upon the lever *L*.

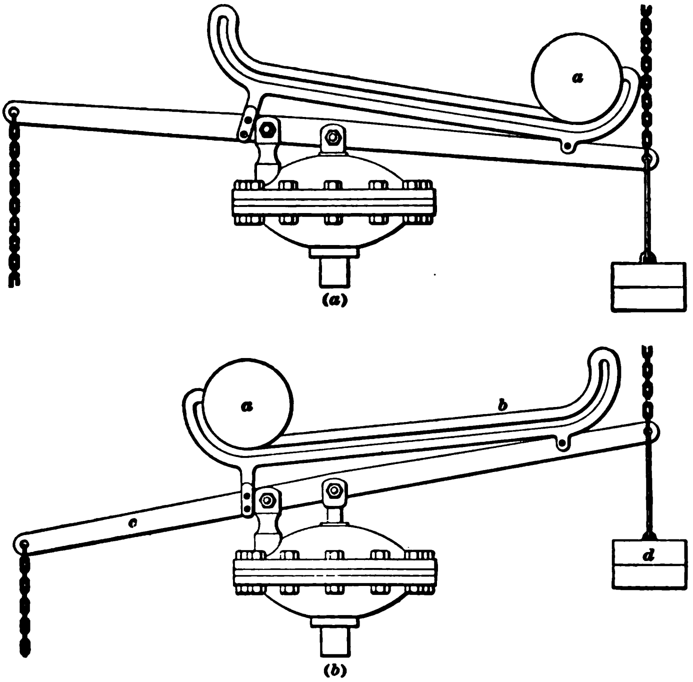

FIG. 659.

In regulators of this class there is a tendency to hold the main-draft damper slightly open, thus causing slow combustion and a consequent waste of fuel. To remedy this trouble and make the movements more decisive, the device shown in Fig. 659 has been designed. It consists of a rolling weight *a*, which is supported upon a track *b*, attached to the main lever *c*, *d* being the main weight; see view (*b*). When the lever is tilted so as to incline the track slightly towards the weighted end, the weight *a* promptly rolls to the extreme end of the track and aids the weight *d* to lift the main draft damper wide open. When the pressure rises sufficiently to lift the lever and incline the track the other way, the ball rolls to the inner end and allows the diaphragm to shut off the draft completely; see view (*a*).

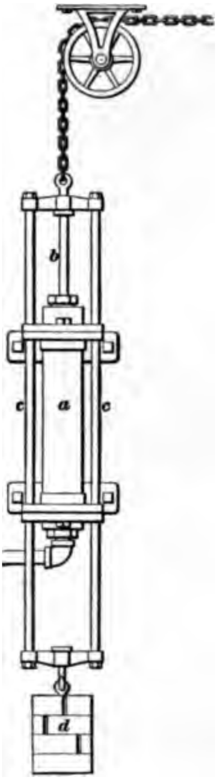

FIG. 660.

1693. A piston regulator is shown in Fig. 660. The cylinder *a* contains a piston which has the full steam pressure beneath it. The piston rod *b* is connected to the dampers by suitable chains and pulleys, and the pressure upon the piston is balanced by the weights *d* attached to the rods *c*, *c*. When the steam pressure overbalances the weights, or the reverse, the piston may travel from one end of its stroke to the other, thus opening the dampers wide or closing them entirely. This mode of operation ensures good combustion and prompt regulation.

BOILER FEEDERS.

1694. The boilers attached to steam-heating apparatus are usually replenished by returning to them all the water of condensation, the pipes being arranged so that it will flow back by gravity. When this is impracticable, the water is returned by means of a *steam pump*, a *return trap*, or a *steam loop*. When fresh feed-water is required, it becomes necessary to employ either a steam pump or an *injector*.

1695. Pumps have been fully described already, so that no further mention is deemed necessary here. Pumps which are to handle hot water must be set so low that the water will flow into them by gravity; otherwise, the suction chamber will fill up with steam and the water will not follow the piston. The valves should be made of metal, because hot water is very destructive to rubber valves.

1696. Return traps are used only for returning the water of condensation to the boiler. It is immaterial whether the pressure in the boiler greatly exceeds that in the heating apparatus or not; they are equally serviceable for all cases. They require to be set above the water-level in the boiler, at a sufficient elevation to allow the water to flow from them into the boiler by gravity.

Fig. 661 shows a very common form of return trap. It is supposed to be set a little higher than the water-level of the boiler, into which it is expected to return the water of condensation from the return mains of a heating system. It is composed of a globe *a* (which performs the duty of a condenser and receiver) and the connecting pipes, to which are attached the valve *b* and check valves *c* and *d*. The pipe on which *c* is placed joins the boiler, usually below the waterline, and the pipe on which *d* is placed joins a receiver which is set at the lowest ends of the return mains to receive condensed water from the heating system.

The pipe on which *b* is placed joins the steam space of the boiler. A rotary slide valve *e* engages, by means of a connecting link *g*, with a rocker *f*, the engaging point between *f* and *g* being provided with slack motion, as shown.

A lever *h*, having a float *i* on one end (inside the trap) and a counterweight on the other, also engages with the casting *f* by means of a slack-motion connection, as shown. A track is formed in the casting *f* along which the solid ball shown may roll.

The action of the trap is as follows: When a vacuum has been formed in the globe *a*, by the condensation of steam, condensed water from the receiver will flow through *d* and into the trap, as shown, and will continue flowing until the trap is full or the receiver empty, providing the trap is not set too high. As the water rises in the trap, the float *i* will rise with it, and the loaded end of the lever *h* will descend accordingly. As this movement of *h* continues, the stud which engages *h* with the casting *f* pushes down that end of *f*, thereby bringing the track nearer to a level position. This it does without moving the rotary valve *e* on the steam connection, because of the slack motion between *g* and *f*.

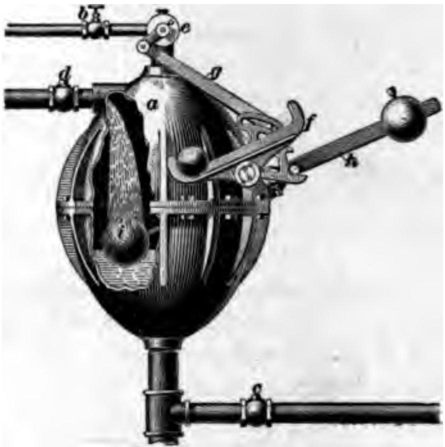

FIG. 661.

As soon as the end of the track on which the ball rests is raised above the level of the other end, the ball will roll along the track, strike the opposite hooked end, and cause it to fall rapidly, opening the steam valve *e* to its full extent. At this point the trap is about full of water, and since the full boiler pressure is now placed on the surface of the water in *a*, and since this water is higher than that in the boiler, it will be easily seen that the water in *a* will simply fall by gravity into the boiler.

As the water drains from *a*, the float *i* will descend, and when it has reached the bottom of the globe, the track will be tilted in the opposite direction by the ball, causing the steam valve *e* to be suddenly closed, when the trap will be prepared to receive another charge from the heating system as the steam condenses in the globe.

The height to which water can be lifted is limited by the difference between the pressure in the receiver and the vacuum formed in the trap. As nearly all varieties of return traps depend upon the formation of a vacuum in order to become filled with water, it is essential that air be carefully excluded from them.

1697. Another method of operating the steam valve, which is used successfully in several varieties of return traps, is to suspend the trap body upon pivots and counterbalance it by a weight. When it fills up with water it overbalances the weight and moves downwards, thus securing the movement required to shift the steam valve. A good example of this mode of construction is shown in Fig. 662. The trap body *a* is pivoted to the stationary part of the trap at *b* and *c*, and is balanced by the weight *d*. As it fills and empties, it vibrates within the guide *g*, and the movement is communicated by the short arm *e* to the steam valve *f*. The supply and discharge pipes are connected at *b* and *c*.

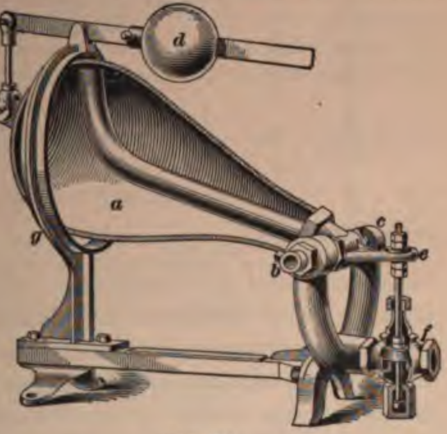

FIG. 662.

1698. The Steam Loop.—This apparatus is designed to return condensed water to the boiler from a lower level, without the use of valves, floats, or other mechanism. It is capable of lifting the water to great distances vertically, and is especially adapted for high-pressure heating systems.

It consists wholly of plain piping, and is constructed substantially as shown in Fig. 663. It consists of a *riser c* and a *drop leg d*, which are connected by a *horizontal* pipe *e*. The riser is connected at its foot with the extreme end of the heating system by the pipe *a*, so that the riser receives all the water of condensation; the drop leg is connected to the boiler below the water-level by the pipe *b*.

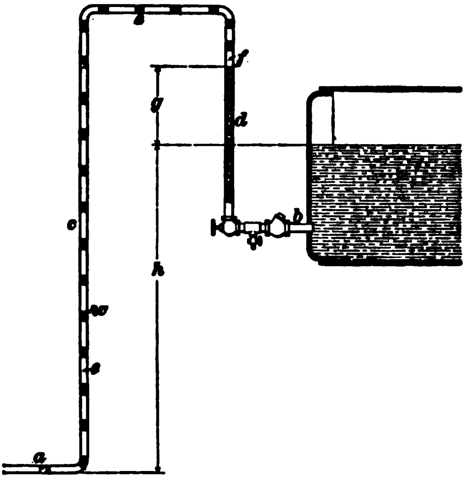

FIG. 663.

When in operation the apparatus becomes filled with bubbles of steam *s*, and slugs of water *w*, and these travel up the riser *c*, thence along the horizontal *e*, and finally descend into the drop leg in endless succession. The cause of the movement is that the steam bubbles are constantly losing their heat and contracting in volume, and are finally condensed in the pipe *e*, or in the upper end of the drop pipe. The pressure in the pipe *a* constantly forces up the contents of the riser and closes the gaps made by condensation; thus the ascending movement continues as long as condensation goes on. The water which is carried up in the pipe *e*, together with that which is formed there by condensation, runs by gravity into the drop leg, where it forms a water-line *f* above the boiler water-line. The pressure due to the head g + the steam pressure already in the pipes becomes greater than the boiler pressure, and so the water in the drop leg flows into the boiler.

The possible height of the riser is limited only to that height at which the weight of its contents will balance the steam pressure in the pipe *a* at its foot. As only a fraction of the contents consists of water, it is evident that the height may be very great. The water, however, will back up in the drop leg until it balances the difference between the pressures in the boiler and in the pipe which joins the bottom of *c*, or the inlet pipe, plus the weight of the contents of the riser; and the actual lift, that is, the vertical distance *h* from the inlet pipe to the water-level in the boiler, will be the difference between these two heights.

1699. The following examples illustrate a good method of computing approximately the dimensions of a steam loop:

EXAMPLE I.—The pressure of steam in the boiler is 30 pounds, absolute, and the pressure at the end of the heating coils, etc., is 20 pounds, absolute. A steam loop is to be used to lift the water of condensation to the boiler; how high may the water-level in the boiler be above the lowest coil or radiator, the proportion of steam to water in the riser being 3 to 1? Consider the weight of a column of water 2.3 feet high and 1 inch square to be 1 pound.

SOLUTION.—The pressure at the foot of the riser will balance a column of water

$$20 \times 2.3 = 46 \text{ feet high.}$$

As the contents of the riser are 3 parts steam to 1 of water, it follows that the column may be 4 times that height, or

$$46 \times 4 = 184 \text{ feet, total height.}$$

The boiler pressure will support a column of water in the drop leg

$$30 \times 2.3 = 69 \text{ feet in height.}$$

The greatest possible lift, supposing the condensation in the horizontal *e* to be perfect, will be

$$184 - 69 = 115 \text{ feet. Ans.}$$

EXAMPLE II.—It is desired to lift the water of condensation 21 feet in order to return it to the boiler; the maximum difference in pressure at the boiler and at the foot of the loop is 7 pounds per square inch. The proportion of steam to water in the riser being 3 to 1, how high must the riser extend above the water-level of the boiler?

SOLUTION.—Supposing the loop to be full of steam only, the water will rise in the drop leg

$$7 \times 2.3 = 16.1 \text{ feet,}$$

to balance the stated difference in pressures. Adding this height to the lift required, we find that the top of the water column will stand

$$16.1 + 21 = 37.1 \text{ feet}$$

above the foot of the riser when the apparatus is in equilibrium. Now, if the riser be filled with mingled water and steam, as stated, the water column must be lengthened to balance it, the additional amount being just equal to the water contained in the riser. As the contents consist of 1 part water and 3 parts steam, it follows that ¼ of the total height will be above the present level of the water column, and ¾ below it. The additional height will, therefore, be

$$37.1 \div 3 = 12.4 \text{ feet.}$$

Adding this to the present height of the water column, the final height above the water-level in the boiler becomes

$$37.1 + 12.4 - 21 = 28.5 \text{ feet. Ans.}$$

In practice, 5 feet or even more should be added to the height, to provide for a possible increase of the difference in pressure between the boiler and the terminal of the heating system. Condensation should not occur in the riser, but only in the drop leg and in the horizontal *e*. The latter pipe serves as a condenser, and may, therefore, be made long or short, as the case may require. In some cases it may be necessary to protect the riser from cooling influences, but the horizontal *e* may always be exposed, being guarded only against freezing.

1700. The formation of the water into "slugs" or pistons becomes uncertain in large pipes, and it is found in practice that the diameter of the riser and pipe *a* should not exceed 1¼ inches, nor be much less than ¾ inch. If the quantity of water to be returned is too great for one pipe, two or more risers may be employed. The diameter of the pipes *c* and *d* is immaterial, and may be made as large as required. A light check-valve, stop-valve, and blow-out cock should be provided at the foot of the drop pipe, about as shown in the figure.

TRAPS FOR STEAM AND AIR.

1701. A **steam trap** is a device for retaining the steam in a heating apparatus while permitting the condensed water to escape. The simplest form of trap is the **siphon trap** shown in Fig. 664. The drain pipe from the radiators, etc., is connected at *a*, and the water escapes from the pipe *b*. When the steam pressure is only equal to the atmosphere, the water will stand at equal heights in the tubes *c* and *d*, but as the pressure increases, the water-level will descend in *c* and rise in *d*, thus overflowing and passing out through *b*. The pipe *e* is an air vent to prevent any possible siphonage. The maximum pressure that can be carried on the heating system depends upon the vertical height of the pipe *d*, while the minimum pressure at which the trap will discharge water depends upon the difference in level of the pipes *a* and *b*. This trap can be used on heating apparatus which works at a pressure below that of the atmosphere, by making the outlet at a lower level than the inlet. Of course, the vertical pipes *c* and *d* may be separated to any horizontal distance without detriment. The principal objection to the siphon trap is that, with high pressure, the pipes *c* and *d* become inconveniently long.

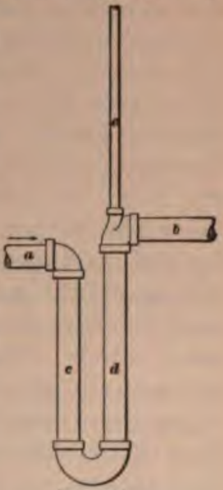

FIG. 664.

1702. Fig. 665 shows a **bucket trap** in section. The condensed water flows by gravity through the inlet pipe *b*, into the trap body *a*, as shown by the arrow. As the water rises in the trap, it floats the empty pot, or bucket, *c* and the spike-valve shown in the center of the pot bottom is forced into the opening at the base of the tube *i*, which leads through *e* to the outlet pipe *d*, and which is really the outlet opening of the trap.

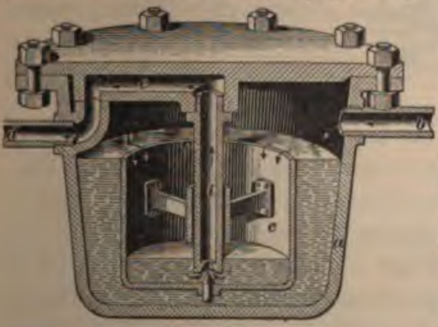

FIG. 665

When the float has risen to its full height, that is, when the spike-valve has reached its seat, the water continues to flow into the trap and will finally overflow into the pot. When the pot is nearly filled with water, it loses its buoyancy and sinks to the bottom of the trap, thereby opening the spike-valve, but as the lower end of *i* is now submerged in water, it follows that the steam pressure within the trap will force the water in the pot up and out through *i*, *e*, and *d*, to the point of discharge. Before the water becomes low enough in the pot to expose the valve opening to the steam, the pot again rises and the spike-valve closes the opening as before, and the trap again fills with water, only to be partly emptied when the pot is again sunk with an overflow of water into it. The reader will thus observe that the action of this trap is *automatic* and *intermittent*. He will also notice that the steam pressure in the trap must be greater than that of the atmosphere; otherwise the water can not be discharged to the outer atmosphere without the aid of some other contrivance, such as a pump, which will draw it, as it were, from the trap and force it into a space of higher pressure—a sewer, for instance.

1703. Fig. 666 shows an **expansion trap.** It is operated by the expansion and contraction of some of its parts, due to changes in their temperature.

When the parts expand, the valve is closed, and when they contract, it is opened again.

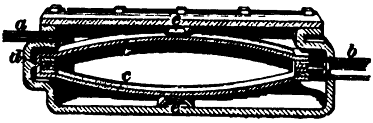

FIG. 666.

These traps, like the bucket traps, differ very much in form, but in all cases the principle is the same; so in Fig. 666 we show the principle rather than the construction.

Steam enters the trap through the inlet *a* and leaves it through *b*. The bent springs *c*, *c* are made of some material which will expand and contract more than the metal of which the body of the trap is made, so that when the temperature of the apparatus changes, the length of the springs will change relatively with the length of the trap body. It will thus be seen that as the ends *d* of the springs are secured to the trap body, expansion or contraction of the springs will move the valve on the other end and so close or open the mouth of the outlet pipe *b*. The bent springs, or expanding rods, *c*, *c* in this figure, are fitted in guides *e*, *e*, to prevent a lateral motion. These guides also prevent the springs from spreading apart, thus giving the greatest possible movement to the valve.

When the water in the trap cools, the rods contract and the valve opens. The water is then forced into the outer air by the steam pressure. When steams fills the trap body, the rods immediately expand again and the valve is closed, thus preventing the escape of steam.

The average expansion trap has certain objections which make it very unsuitable for removing water from steam-heating systems. They are usually so delicate in construction, and require to be regulated so nicely, that they often get deranged by foreign matter in the water sticking in the valve, etc.

Bucket traps, operating on a principle similar to Fig. 665, have been found to give the best results when applied to steam-heating apparatus. All steam traps require periodical inspection; otherwise, they are liable to become clogged and cease to operate properly.

The traps, Figs. 665 and 666, will raise the water to a height corresponding to the steam pressure in the trap; consequently, if they are used with high-pressure steam, the water may be raised to a considerable height, but they can not return the water to the boiler whence it came in the form of steam.

It should be noted that those traps which are controlled by the *temperature* instead of the weight of their contents will discharge *air* from the heating apparatus as readily as water, if properly connected. In this respect they possess a great advantage over all other kinds of steam traps. In fact, nearly all air traps are constructed on the same principle.

AIR VENTS AND TRAPS.

1704. All air vents or traps on steam-heating systems are thermostatic in principle, and are controlled by a difference in temperature between the steam and the air which is to be expelled from the heating apparatus.

Fig. 667 shows the construction of an ordinary **air vent.** The shank *a* is screwed into a radiator tube, and the nozzle *d* is connected to a suitable drip-pipe. The valve *c* is a rod composed of some expansible material which is adjusted against the steam orifice by means of the screw *b*. When air instead of steam enters the orifice *e*, the rod *c* cools off and shortens slightly, thus opening the orifice and permitting the air to flow through. As soon as hot steam arrives, however, the rod expands, and again closes the vent.

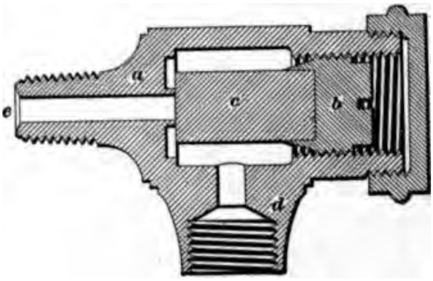

FIG. 667.

The length of the expansible part which is exposed to the air or steam is very small; consequently, the opening of the vent will be very slight, and quite slow in operation. This is improved in the mode of construction shown in Fig. 668. The expansible rod *a* is much longer and is hollow. Its whole interior surface is exposed to the steam or air at all times. The lower end is screwed fast to the body of the vent, and the upper end draws away from the valve *b*

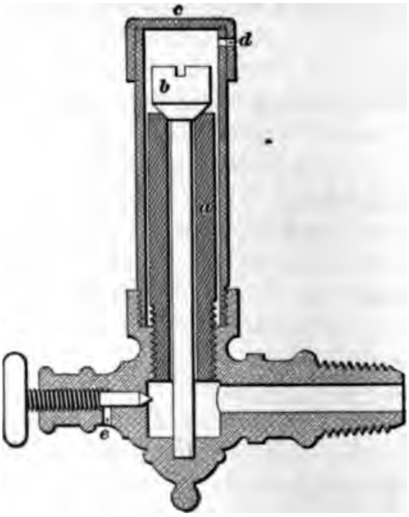

FIG. 668.

when contraction occurs from the cooling influence of the air. The valve *b* has a long stem which screws into the bottom of the chamber, and is easily adjusted by means of a screwdriver when the cap *c* is removed. The air passes out through the vent-hole *d*. A small screw valve *e* is added for relief by hand when desired.

1705. Both of the devices shown will permit the escape of water as readily as air; therefore, they should be provided with suitable drip-pipes. Otherwise, they are very liable to discharge water at almost any time, and thus make serious trouble.

In Fig. 669 this trouble is remedied by attaching a cup or float *a* to the stem of the air valve *b*. This stem rests loosely upon the bent spring *e*, and when the chamber fills up with water, the float will lift the valve and close the vent. The valve is opened to discharge the air through a small opening in or under the cap *c* by the bending of the spring, which is made of two strips of different metals firmly soldered together. These contract by different amounts when cooled, thus bending the spring and allowing the valve to open slightly.

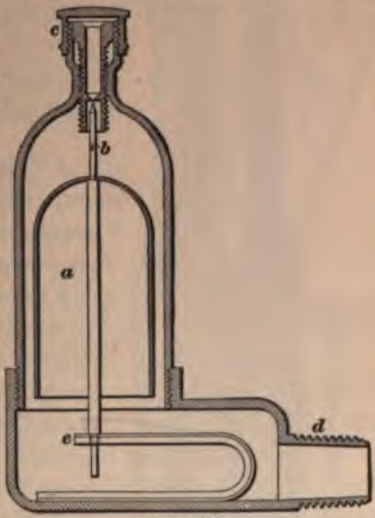

FIG. 669.

The proper place to attach an air vent to a radiator or coil is at a point as far as practicable from the steam inlet, so as to prevent the current which moves towards the vent from carrying hot steam to it, and thus closing it before all the air has escaped.

Some air vents are made with specially long nipples instead of short ones, as at *d*, and a rim is sometimes left on the end to throw water clear of the nipple opening.

STEAM SEPARATORS.

1706. Steam which is wet can be separated from the entrained water and dried by mechanical means. This is accomplished by compelling the steam to change the direction of its flow abruptly, while moving at a moderately high velocity. The steam is so mobile that it turns a sharp corner very readily, but the particles of water are comparatively heavy and have so much momentum that they continue to move in their original direction, and thus separate themselves from the steam.

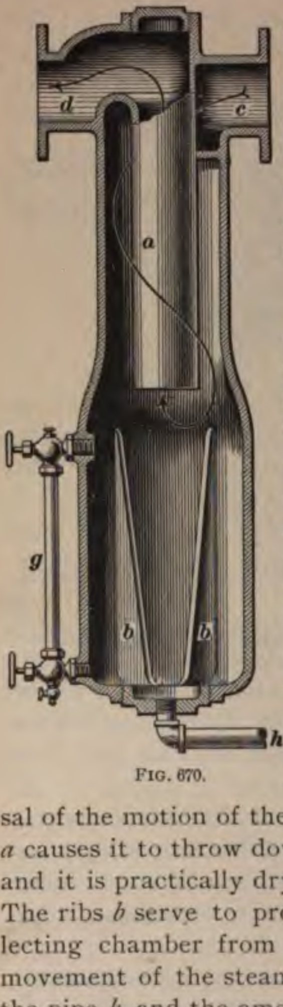

FIG. 670.

1707. Steam separators are constructed in a great variety of ways, but all of them operate upon the same general principle. Fig. 670 shows one which is known to be very efficient. The steam enters at *c* and passes spirally downwards around the central tube *a*, and is then compelled to abruptly reverse its motion and pass up inside the tube to the outlet *d*. The momentum of the entrained water causes it to strike the outer walls of the chamber, to which it adheres, and trickle down into the collecting chamber below. The sudden reversal of the motion of the steam at the lower end of the tube *a* causes it to throw down the last drops of entrained water, and it is practically dry when it passes from the outlet *d*. The ribs *b* serve to prevent the water or steam in the collecting chamber from being whirled about by the rotary movement of the steam. The water is drained off through the pipe *h*, and the amount present in the chamber is shown by the gauge glass *g*.

Separators are also used for removing oil or grease from exhaust steam. The mode of operation is exactly the same.

1708. Exhaust heads are a variety of separators which are especially adapted for attachment to the top of exhaust pipes from engines and pumps, and serve to catch the water of condensation and prevent it from being scattered promiscuously over roofs, etc., in the vicinity of the exhaust pipe outlet. The principle of operation is the same as in steam separators, but the construction is modified somewhat to suit the conditions of the case.

Fig. 671 shows one which is in common use. The steam enters through the pipe *a*, passes up through the divergent branches *b*, and blows through the short open nozzles *c* against the top head *h*. It then passes down through the cone *d*, and, after making a sharp turn at the bottom of the cone, finally escapes up the tube *g*. All the surfaces on which water is likely to lodge are arranged so that it will drip into the collecting chamber *e*. At one side of the chamber a drip-pipe *k* is attached, to conduct the water away to some convenient point of discharge.

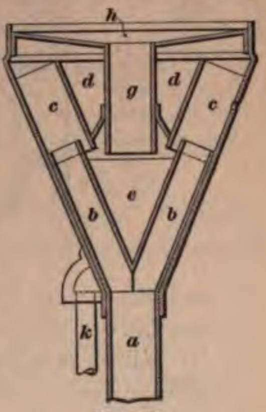

FIG. 671.

REDUCING VALVES.

1709. These valves are used for reducing steam from any given pressure to a lower pressure. There are three classes of reducing valves, which are distinguished by their mode of operation: *First*, those which maintain a *uniform low pressure* at the outlet, regardless of the fluctuations of the original pressure. *Second*, those which maintain only a *constant difference* in the pressures at the inlet and outlet. *Third*, those which maintain a *constant ratio* between the initial and reduced pressures.

1710. A valve of the *first* class is shown in Fig. 672. The steam enters at *a*, and is delivered at *b*. The valve *c* is double seated, and the areas of the openings are equalized as nearly as practicable, so that the steam has little or no tendency to move the valve either way. The steam which has passed through the valve acts upon the under side of the diaphragm *d*, and tends to raise it and thus close the valve. The valve is opened by the adjustable weight acting on the spindle through the lever *e*. It will be seen that this weight, after being set in any particular point, does not vary, and that it is lifted only by the steam on the *low pressure side* of the valve; therefore, the weight being constant, the pressure must be constant also, in order to balance it.

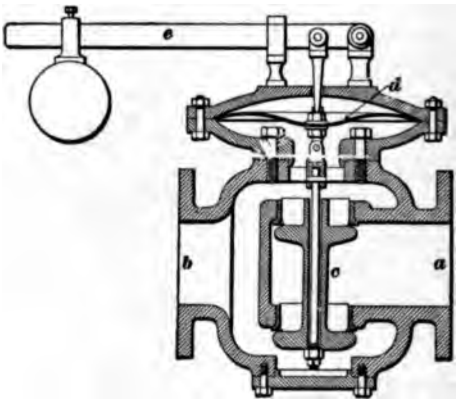

FIG. 672.

As soon as the effect of the weight preponderates, it opens the valve and admits high-pressure steam, until the pressure rises sufficiently to lift the diaphragm.

The material used for the diaphragm is usually copper or phosphor bronze. If rubber is used, the valve must be inverted so that the diaphragm will be covered with water, because the rubber can not long endure the contact of live steam.

1711. A valve of the *second* class is shown in Fig. 673. The valve seats are of different diameters, so that the high pressure steam entering at *a* acts upon the differential area and tends to open the valve. This is resisted by the low pressure steam upon the delivery side, and by the balance weight *b*. It will be seen that the weight contends not with the reduced steam, but with the high pressure steam on the inlet side, and that its resistance is practically constant at any particular setting. Therefore, it can counterbalance only a certain amount of the initial pressure of the steam. The excess of steam, if any, will pass through and increase the pressure on the outlet side. If the initial pressure falls, the reduced pressure will also fall until there is a difference between them just sufficient to balance the weight. Thus the valve tends to maintain a practically *constant difference* in the pressure on its opposite sides.

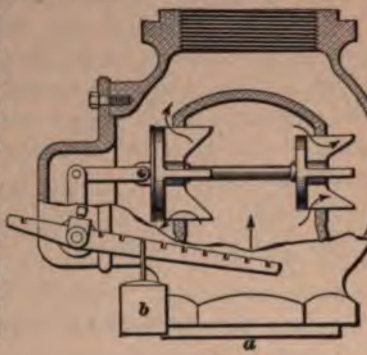

FIG. 673.

1712. A valve of the *third class* is shown in Fig. 674. The valve c is a large flat disk, and the seat is also perfectly flat. The steam enters at a and passes up through the central hole d and flows outwards in a thin sheet between the valve disk and its seat, expanding down to the low pressure desired by the time it reaches the edge of the disk and before it enters the low pressure chamber b. The reduced pressure acting upon the entire upper surface of the valve is balanced by the initial pressure acting upon the under side on the area of the hole d plus some expansive force of the steam flowing between the valve and its seat. Thus the pressures on the opposite sides of the valve must always be in about the same ratio as the areas of the valve disk and the central

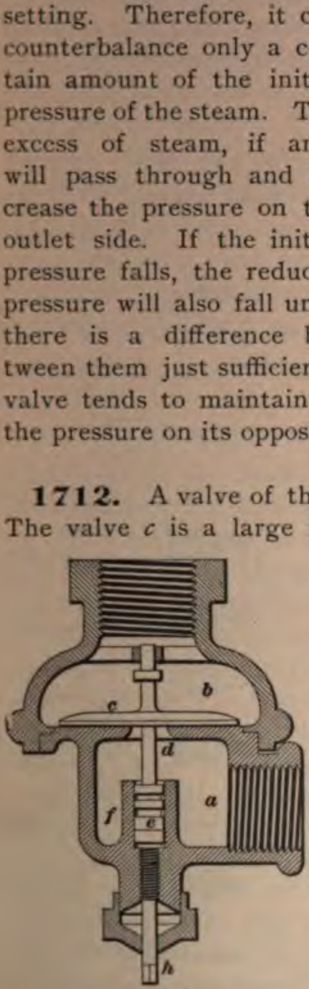

FIG. 674.

hole. If the pressure rises in the outlet, it forces the valve down and diminishes the flow of steam; and if the pressure falls off, the steam in the inlet will lift the valve and increase the supply until the pressure rises to the desired point. Thus a *constant ratio* will be maintained between the pressures in the boiler and in the heating system. The stem of the valve is provided with a piston *e* which moves inside a cylinder *f*, and a set screw *h* is used to prevent *c* from being closed entirely. A cushion at *c* will help to make the valve noiseless.

SPECIAL STOP-VALVES.

1713. Fig. 675 shows a **diaphragm valve** of a type commonly used on radiators in steam-heating systems which are automatically controlled by thermostatic apparatus. It is of ordinary construction, except that the stem slides instead of rotating. The diaphragm *a* actuates the valve by means of compressed air which, when admitted into the chamber *b*, presses the valve down upon the valve seat *c*.

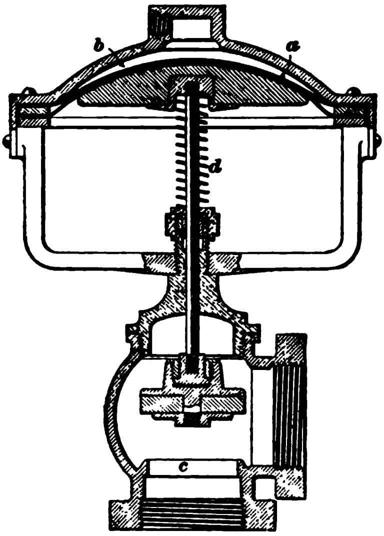

FIG. 675.

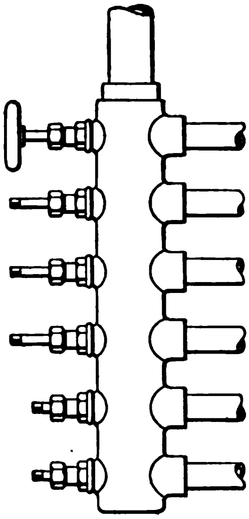

FIG. 676.

The spring *d* causes the diaphragm to return and lift the valve when the air pressure is released. It will be noted that the valve is held closed only so long as there is sufficient air pressure in the chamber *b*. The admission or release of the compressed air is governed by the thermostat.

1714. Pipe coils for steam or hot water are sometimes made with **valved manifolds,** such as shown in Fig. 676. Each branch is controlled by an ordinary valve disk and spindle, such as is used in globe valves. By means of this arrangement any desired portion of the coil may be shut off and rendered inoperative.

SPECIAL FITTINGS.

1715. Fig. 677 shows a fitting designed to make a connection between a radiator branch and a continuous riser. The partition *a* is curved so as to secure a proper supply to the radiator, and the passage *b* permits the main current to ascend without excessive obstruction. It is intended to take the place of the common fittings which are usually employed for the same purpose, as shown in Fig. 678, and it also has the advantage of preserving the alinement of the parts of the riser. Fig. 679 is a variety of **T Y** which is designed for the same, or a similar purpose, as Fig. 677. Fig. 680 shows an **eccentric reducer,** which serves to bring the bottoms of the connected pipes to the same level, and thus prevent the lodgment of water at that point. This is particularly useful on steam mains and other steam pipes that are nearly horizontal.

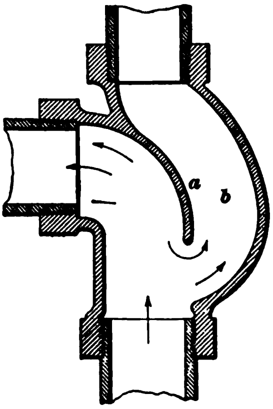

FIG. 677.

1716. Fig. 681 is a **cross** or double **T** having the branches at a higher level than the main pipe. This form of connection ensures the proper drainage of the branches into the main steam pipe, and also prevents condensed water in the bottom of the main from entering the branches.

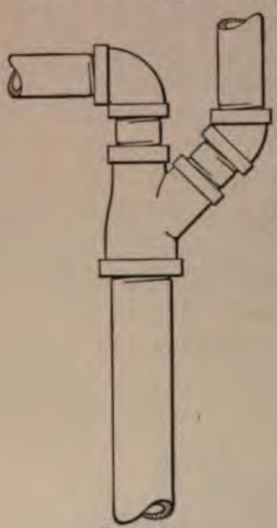

FIG. 678.

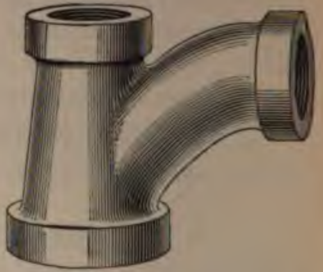

FIG. 679.

EXPANSION JOINTS.

1717. The iron pipes which are used in steam and hot-water fitting expand about 1½ inches per hundred feet in length. In long lines of pipe this expansion must be provided for; otherwise, it will make trouble by breaking connections or shoving apparatus out of place. In large pipes the expansion may be taken up by means of a **sliding joint,** such as shown in Fig. 682.

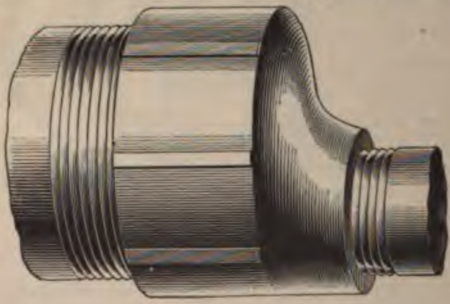

FIG. 680.

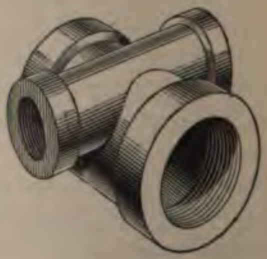

FIG. 681.

A is the body into which a brass bushing *B* is forced; into the latter is fitted the sliding tube *C*. Packing is placed in the stuffing-box *D*, and is held in position by the gland *E*, the gland being screwed down by means of bolts. The packing is put in to prevent the leakage of steam. *F*, *F* are studs which limit the amount of movement of the sliding tube *C*. The flanges *G* and *H* are bolted to the flanges of the pipe; consequently, when the pipe expands, the body of the expansion joint is forced to the left, and the sliding tube to the right, and when it contracts they are forced in opposite directions.

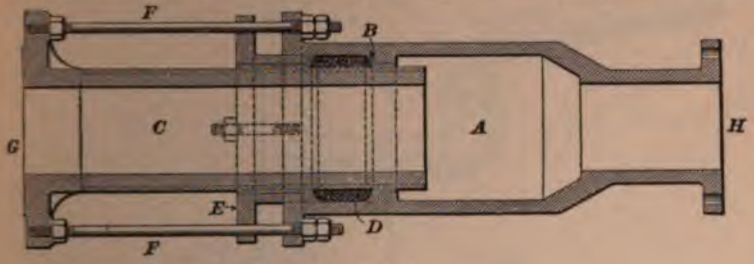

FIG. 682.

1718. An expansion joint in a line of steam pipe must, according to what has just been said, allow of 1½ inches movement for every hundred feet in length of pipe.

These sliding expansion joints are generally objectionable because of the care required to keep the packing tight and in good order. The sliding tube should be made of brass or bronze, to prevent it from corroding and so sticking fast.

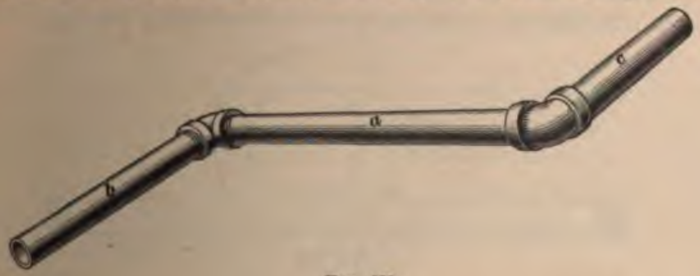

FIG. 683.

1719. Other modes of providing for the linear expansion of pipes, especially in the smaller sizes, are shown in Figs. 683 to 686. In Fig. 683 an offset is made in the pipe, and the piece *a*, which is called a **spring piece**, is made long enough to bend or spring sufficiently to permit the necessary movement of the pipes *b* and *c* without straining the threads excessively or cracking the fittings.

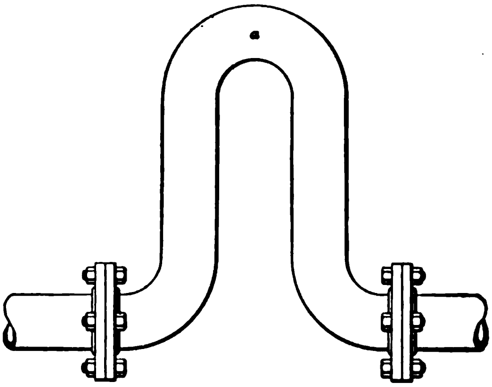

FIG. 684.

1720. In Fig. 684 the spring piece *a* is bent up into a **loop,** as shown. Pipes of this kind are usually made of copper, with brass flanges brazed on.

1721. In Fig. 685, the pipe *a* is bent into a **coil.** This form affords such an easy bend that ordinary wrought-iron pipe may be used without difficulty. The diameter of the circle should be large enough to permit the desired amount of spring without serious straining.

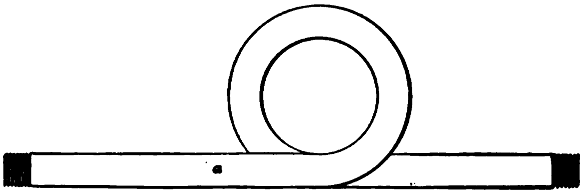

FIG. 685.

1722. In Fig. 686, the connections are made so as to **swivel** instead of bend. When the pipes *b* move endways by expansion, the nipples *c* will turn slightly in their threads, and thus permit the piece *a* to swing to the requisite extent.

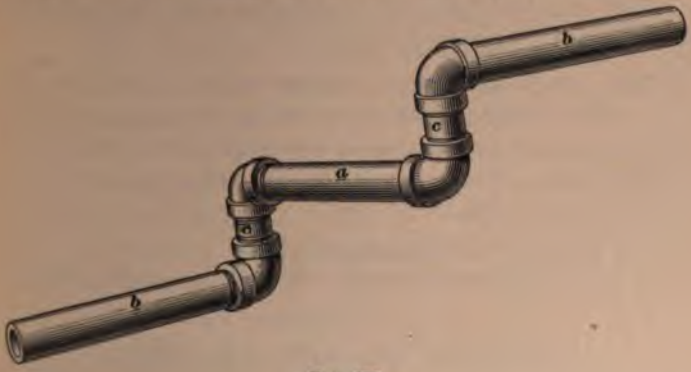

FIG. 686.

Care must be taken in using the devices shown in Figs. 684 and 685 to avoid forming a pocket in which water or air may collect. A pocket may usually be prevented by extending the loop or coil horizontally instead of vertically.

STEAM-HEATING SYSTEMS.

STEAM AS A HEATING AGENT.

1723. The comparative value of steam as a heating agent varies greatly with its condition, whether wet, dry, or superheated, and also with its pressure, whether high or low. The steam serves principally as a transmitter of heat from the boiler to the radiators; and to perform this function to the best advantage it should contain the greatest practicable amount of heat per cubic foot.

1724. **Wet steam** contains less heat per pound, and also per cubic foot, than dry or normal steam; therefore, a larger volume and weight will be required to transmit a given amount of heat than when dry steam is used. It also produces more water in condensing, and the liability to trouble from water hammer is much greater; therefore, extra care must be taken to thoroughly drain the pipes and radiators in any heating system where it is used.

1725. Low-pressure steam contains less heat than high-pressure steam, when measured by the pound, but the difference is very much greater when they are compared by the cubic foot, as shown by the following figures, taken from the steam tables:

TABLE 70.

	Pressure per Cubic Foot. Wet.	Pressure per Cubic Foot Dry.	Difference.
Steam pressure, absolute ...	10	74	64
B. T. U. per pound.........	1,172.89	1,207.43	34.54
B. T. U. per cubic foot.....	31	209.3	178.3
Temperature..............	193.28°	306.52°	113.24°
Volume per pound.........	37.83	5.767	32.063

It will be seen that the quantities of heat contained per cubic foot are in the ratio of about 1 to 7, and that this ratio is nearly the same as that between the absolute pressures. Therefore, the volume of steam which must be moved through the pipes and radiators, in order to transmit a given amount of heat, is much greater at low than at high pressures.

The radiators must also have a greater area of emitting surface, because the temperature of the low-pressure steam is so much less. Thus, in the case given, if the radiators were used to heat air having an average temperature of 55°, they would emit heat in the following proportion:

$$(306.52 - 55 = 251.52) : (193.28 - 55 = 138.28) = 1.8 : 1;$$

therefore, the low-pressure radiators would require about 80 per cent. more emitting surface than the high-pressure ones, to do equal work.

1726. The disadvantages incidental to the use of low-pressure steam may be partially overcome by **superheating** it. For example, if steam at 10 pounds pressure, absolute, is superheated 113°, it will have the same temperature as normal steam at 74 pounds, absolute. The emitting surfaces of the radiators may then be of the same area. The amount of heat contained per cubic foot, however, will be increased only from 31 to 32.4 B. T. U., or about 5 per cent.; consequently, the area of the distributing pipes could not be diminished by any considerable amount.

CIRCULATION OF STEAM.

1727. The term "circulation" implies a continuous movement in an endless circuit. The movement of the fluid in a hot-water system is of this character, but the movement of the steam in an ordinary steam-heating system is of a different kind, being always in one direction until it ceases to exist.

The return pipe which is commonly provided merely serves to convey the water of condensation back to the boiler, thus acting as a feed-pipe to supply material for the formation of new steam, but it does not afford any opportunity for the steam to return to the boiler as steam and be reheated.

A steam-heating system will work perfectly without a return, provided that the water of condensation is drained from the apparatus. Whether this water should be returned to the boiler or be thrown away is merely a question of economy, and does not affect the supply of steam to the radiators. The water contains a considerable amount of heat, which may be saved by returning it to the boiler, and it is also clean and pure, and, therefore, much better for steam making than ordinary fresh feed-water.

The difference between the pressures existing at the boiler and at the various radiators is due solely to the resistance which the supply pipes offer to the flow of steam through them. If this resistance could be completely abolished, the steam would flow instantaneously to any point where the pressure was lowered. Thus the pressure would be perfectly and continually equalized throughout the whole steam system. A fall of pressure can not occur at any point unless the flow of steam to it is in some way obstructed.

DRAINAGE.

1728. *Steam will part with its heat only by condensation.* No matter how small the amount of heat emitted, a corresponding amount of condensation must take place. If the steam is superheated, however, no condensation will occur until this extra heat is exhausted and the steam reduced to the dry or normal condition.

If the amount of condensation is small, the water may remain suspended in the steam, making the steam wet; but if the amount is considerable, part of it will precipitate upon the walls of the enclosure, trickle down, and accumulate in a pool of liquid.

Steam heating can not be performed without the formation of water, and if this water is allowed to accumulate it will obstruct the supply of steam and stop the emission of heat. Therefore, its prompt and thorough removal is a matter of great importance. All pipes which supply steam must be carefully **graded,** so that the water will flow by gravity in the proper direction. Care must be taken to avoid the formation of pockets, or depressions, in which water may collect. Return pipes should also be inclined so as to discharge the water by gravity into the drip pipes, and should also be free from depressions or pockets.

1729. Water Hammer.—The hammering noises frequently heard in steam pipes are caused by the violent collision of bodies of water, either with each other, or with the elbows and other fittings which change the direction of the flow, or with the end of the pipe or chamber.

When water is carried along through a pipe by a current of steam, the water has a tendency to form into "slugs," which fill the bore of the pipe and move along like pistons. When there is a partial vacuum in front of one of these slugs, the pressure behind the slug drives it forward at high velocity like a projectile. When it strikes an obstruction, it produces a concussion like any other projectile.

It is sometimes quite difficult to locate the point where water hammer occurs, owing to the fact that the metal pipes are good conductors of sound, and that they transmit the shock and vibration to long distances. The sound is very deceptive, because the vibrations may travel a great distance along a pipe which is muffled, and will come out loud and clear at some other point where the pipe is exposed.

Water hammer and sizzling noises are results of bad drainage, and they can always be cured by correcting the drainage system.

1730. Water pockets are very dangerous in pipes through which steam flows at high velocity. Ordinarily the water will accumulate quietly until the pocket is full, when the current will suddenly pick up a part of the water, sometimes all of it, and carry it forwards in a compact mass. This body of water moves with the same velocity as the steam, and when it arrives at an elbow or T, where the direction of the flow is changed abruptly, it strikes the fitting like a projectile, and the blow is often sufficient to crack the fitting, or even break it.

A water pocket in a steam pipe which supplies an engine is particularly dangerous, because the water is likely to go over into the cylinder in a flood. This usually results in a "smash-up," because the engine is not provided with drainage apparatus of sufficient size to handle so much water.

PIPING SYSTEMS.

1731. The principal systems of piping which are now in vogue for heating purposes are shown in Figs. 687 to 690. These diagrams are intended to illustrate only the genera arrangement of the piping, and many details are therefore omitted. The radiators *a*, *b*, *c* are supposed to be located on different floors and at various distances from the vertical supply pipes or risers. It will be seen by careful inspection of the diagrams that the main difference between the several systems consists in the method of returning the water of condensation to the boiler.

1732. The **one-pipe system** is shown in its simplest form in Fig. 687. Steam flows from the boiler *B* through the riser *s*, and is conveyed to the radiators through suitable branches, which are nearly horizontal. All the condensed water flows backwards through the same pipes, moving in a contrary direction to the steam. All of the (nearly) horizontal pipes, such as *h* and *e*, must, therefore, be inclined sufficiently to secure the ready movement of the returning water.

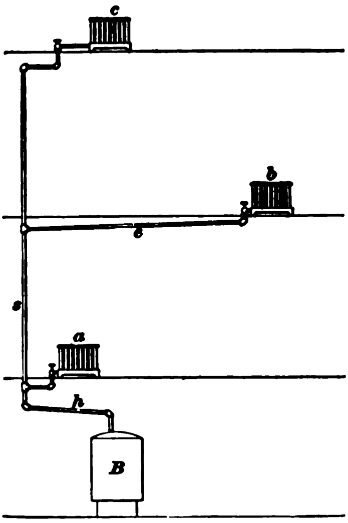

Fig. 687.

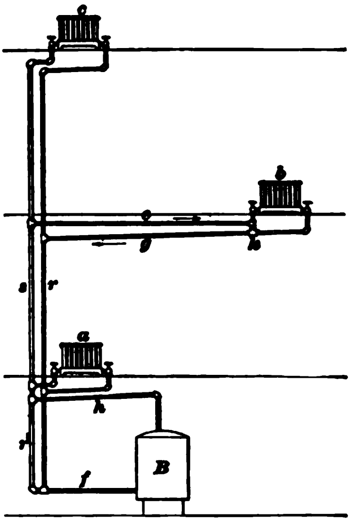

Fig. 688.

1733. The **two-pipe system** is illustrated by Fig. 688. Each radiator has two connections, one of which serves as an inlet for steam, and the other as an outlet for water. The steam supply passes through the pipes *h* and *s*, and the water flows back to the boiler through the return pipes *r* and *f*. The branch *e* which supplies steam to the radiator *b*, at a considerable distance from the riser, is inclined so that the water formed within it will flow towards the radiator. It is connected to the return pipe *g* by a small relief pipe at *k*, so that the water will be drained off and prevented from entering the radiator. The steam main *h* is also inclined, if it is of any considerable length, so that the water formed within it will run towards the foot of the riser *s*. All the water formed in the pipes *h* and *s* is drained off by the *relief pipe r'*. Thus the steam and the water are carefully separated at all points in the system.

1734. The **separate-return system** is shown in Fig. 689. The steam supply pipes are the same in every respect as in Fig. 688. The returns, however, are different, each radiator being provided with its own separate return pipe, as shown at *r r' r''*.

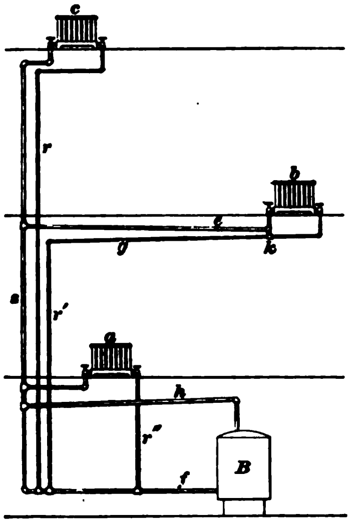

FIG. 689.

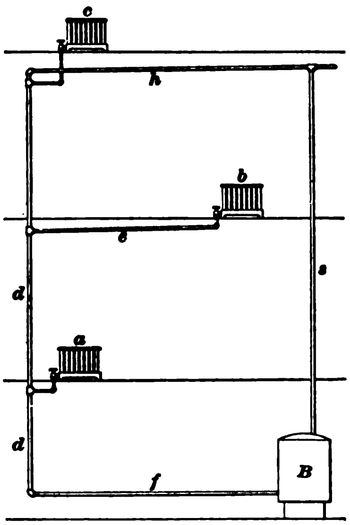

FIG. 690.

1735. The **drop system** is shown in Fig. 690. The steam supply passes up the riser *s* to the top of the system, thence along the horizontal pipe *h*, and descends through the drop pipe *d*. The radiators are connected to the steam supply with single pipes, precisely as in Fig. 687. It will be seen that the water in the pipes *h* and *d* moves in the same direction as the steam, instead of in the opposite direction, as in the single-pipe system. It is not necessary that the returns should be made parallel with the steam supply pipes, as shown in Figs. 688 and 689, but they may follow any convenient route back to the boiler. It is always advisable to make the returns as direct as practicable, care being taken, however, to avoid straggling the pipes about the building in an unsightly fashion.

The "circulation," that is, the supply of steam, is far more certain in the two-pipe system than in the one-pipe system, because there is nothing to oppose or interfere with it at any time. Thus, a radiator at the end of a long horizontal branch, as at *b* in Fig. 687, is liable to have its supply interrupted by the formation of the returning water into "slugs," filling the bore of the pipe, as already explained. But, when the pipes are arranged as in Fig. 688, the same formation may occur without causing any trouble whatever.

When steam and water flow in the same pipe, the steam is likely to be wet, because the separation is less complete than when they are kept apart. When the currents flow in contrary directions, the wetness of the steam is aggravated, and there is such an amount of mechanical interference between them that larger pipes are required than would otherwise be necessary, and there is also much greater liability to water hammer and sizzling noises.

Occasionally a radiator will gradually fill up with water. This occurs, in a one-pipe system, when the steam valve remains nearly closed for a considerable time, but not shut tight. The steam is then condensed as rapidly as it enters, and the opening is so restricted that no water will escape. The same thing will happen in a two-pipe system if either of the valves is closed and the other remains open. By opening both valves wide, the water will almost noiselessly pass out into the return; but in the one-pipe system, as soon as the valve is opened, a violent struggle will begin between the entering steam and the escaping water. The result will be a succession of rumbling, hammering, and snapping noises, which will continue for several minutes. If the supply pipe is long, as at *e* in Fig. 687, the noise is likely to be prolonged to an annoying extent.

In a large heating system the amount of water to be returned to the boiler is so great that it becomes very difficult to pass it back through the steam supply pipes without seriously interfering with the flow of steam to the radiators. The difficulty reaches a maximum in the coldest weather, the greatest amount of condensation occurring at the same time that the largest supply of steam is required. A single-pipe system must be carefully planned to avoid failure at this critical time, and it is good policy to attach returns at some of the principal points to intercept the water and prevent it from flooding the risers.

The two-pipe system, however, when carried out completely, has a certainty of operation and freedom from noise which, in many cases, makes it much superior to the one-pipe system.

1736. Subdivision of Systems.—It is advisable to divide all heating systems which are of any considerable extent into several independent sections. Long horizontal branches which are liable to give much trouble may be reduced to a minimum by employing independent or special risers, and carefully locating them where they will supply the largest number of radiators to the best advantage. One riser may be used to supply almost any number of radiators, provided that none of them are located so far away from it as to make it difficult to drain the supply branch. Thus the question of the number of risers to be employed will be determined mainly by considering the drainage in the horizontal pipes.

In a very tall building, a single riser may be sufficient, provided that the floors are of moderate dimensions; but, if the building covers a large area of ground, two or more risers will be required. In all cases, however, it is advisable to have the branches as short as possible.

Each section of a heating system should be made *independent* of the others, so that it can be closed down for repairs without affecting any other part of the system. Large straightway or gate valves should be placed in both the supply and return riser connections, close to the mains.

DESIGNING A PIPE SYSTEM.

1737. In planning any system of steam pipes, there are two things which must be kept always in mind and be fully provided for; these are **drainage,** and the movement of the pipes by **expansion.** No heating can be done without condensation taking place, and the water thus produced must be disposed of promptly and completely, and in a manner which will prevent interference with the steam supply.

Expansion and contraction are inevitable, and the movement is repeated every time the system undergoes any considerable change in temperature. This movement must be provided for; otherwise, it will break the joints and make serious trouble.

1738. The general arrangement of a **steam main** to supply several risers is shown in Fig. 691. The boiler *a* is set on the cellar or basement floor, and furnishes steam to the entire system. The steam main *b*, whose duty it is to convey steam to the several risers *c*, through which it flows to the radiators *d*, *d*, etc., placed inside the rooms to be warmed, is connected to the steam space of the boiler, and is so suspended from the floor joists by hangers that it will have a uniform fall from its highest point, which is immediately above the boiler, to its lowest point *f*. A pitch of about half an inch in ten feet is usually considered sufficient fall for the main. When steam is generated in the boiler it is forced into the steam main, from there into the risers, and thence into the radiators. The air which the pipes contain is forced out of the system into the atmosphere through air vents or small valves placed at suitable points in the system, usually upon each radiator at the end opposite the steam inlet. As steam flows through the main and risers, part of it will be condensed by heat being transmitted through the pipes to the air and surrounding objects. This condensed steam will gravitate to the bottom of the steam main, flow to its lower

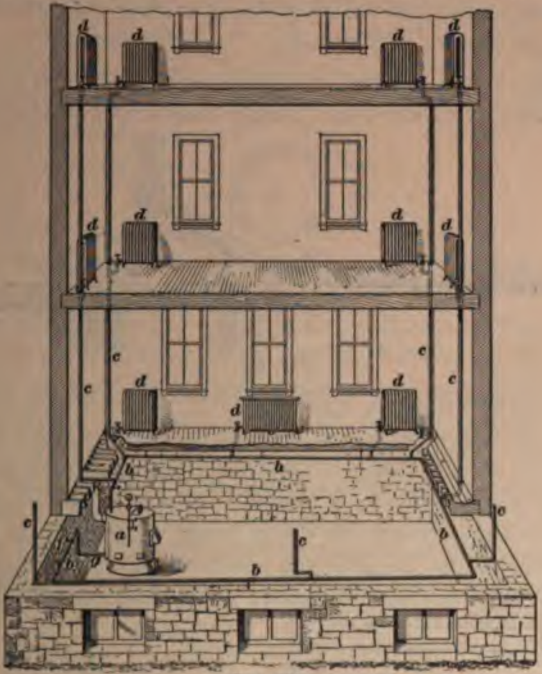

FIG. 691.

end *f*, and enter the bottom at the boiler through the return pipe *g*. The condensed water first accumulates in the base of the radiators until a sufficient hydrostatic head is formed to cause it to flow out of them against the inflow of the steam. It then falls down the risers, through the riser connections, and into the steam main, also against the flow of the steam. If the riser connections to the steam main or the radiator connections to the riser have too little pitch, or if the pipes are too small, the flow of the condensed water through them will be resisted so much by the flow of steam that the water will not flow off as quickly as it is formed, the result of which will simply be that the water will accumulate in the pipe until it entirely closes the caliber, when water hammer will take place. The steam main should be made sufficiently large to prevent such a difference between the pressure in the boiler and that at the point *f* as would cause the water to back up in the main and retard the flow of steam to any riser connection.

1739. In many cases, it is advisable to connect the steam pipe leading from the boiler to the mains at a point near the middle of their length, as at *a* in Fig. 692. The pipes may then be graded downwards from *a* in both directions.

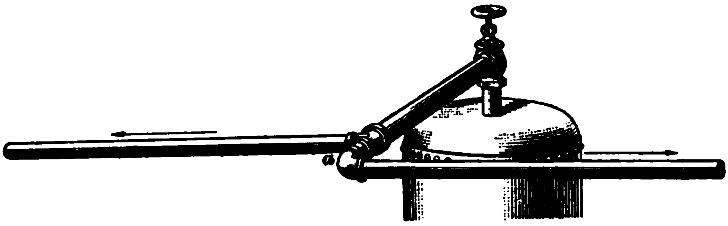

Fig. 692.

When a main or any horizontal steam supply pipe has to be run a long distance, it becomes impracticable to grade it uniformly throughout its whole length, because the far end drops too low to be drained conveniently. In such a case the difficulty may be overcome by introducing *vertical offsets*, or **relays**, in the line of pipe, as shown in Fig. 693. A relief pipe may then be attached at the foot of each offset, as at *a*. The steam should always flow down grade—that is, in the direction of the arrows.

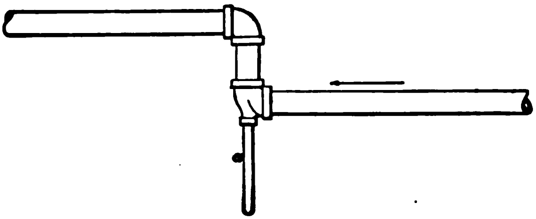

Fig. 693.

1740. The **riser connections,** or the nearly horizontal pipes between the steam main *m* and the foot of the risers *r*, in one-pipe systems may be made as shown in Fig. 694 or 695. They permit the mains to be kept away from the foundation walls sufficiently to allow them to be got at conveniently for screwing together and also for putting on coverings, etc.

The piece *a* serves as a spring piece, and permits both the main and the riser to shift slightly by expansion. In Fig. 694 the spring piece is bent, to ensure good drainage. The construction shown in Fig. 696 is sometimes used for the same purpose, the grade being secured by cutting the thread crooked at the end *a*. This is bad practice, because the teeth of the dies cut too deeply into the pipe on one side and weaken it seriously.

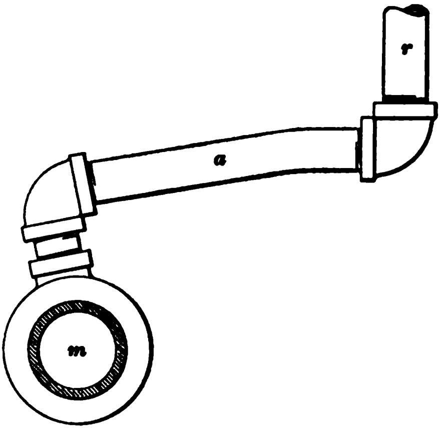

FIG. 694.

A riser should not be connected directly to the top of the main by a **T**, unless both pipes are very short. If the riser is long, its weight will cause the main to sag, and if the connections to the radiators above are rigid, the downward expansion will either bend the pipe or lift the radiators.

The connections to radiator branches, etc., should, if possible, be made with **Y** fittings.

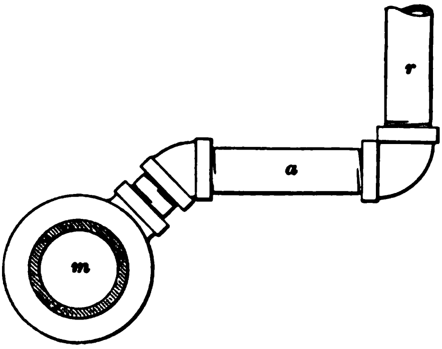

FIG. 695.

Plain **T** connections are objectionable in a one-pipe system, because the condensed water runs down upon the interior surface of the riser, and is very apt to flow outwards into the branch thus increasing the difficulty of draining it properly.

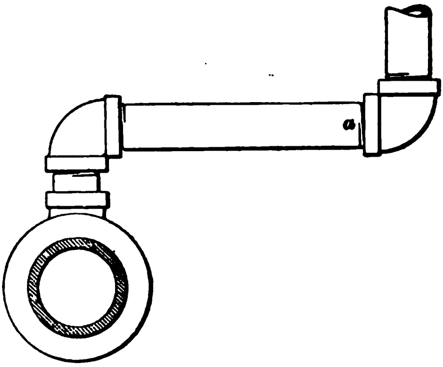

FIG. 696.

In the case of risers which are very high, provision must be made for expansion. This may be done by making horizontal offsets in the pipe, at intervals not greater than two stories apart. If the weight is considerable, the riser must be supported by some other means than its connections to horizontal branches.

1741. Radiator Connections.—The ordinary mode of connecting a radiator to the riser in a one-pipe system is shown in Fig. 697. The pipe *a* serves as a spring piece to allow the riser to expand without lifting the radiator, and the drop *b* ensures that the water shall drain away readily.

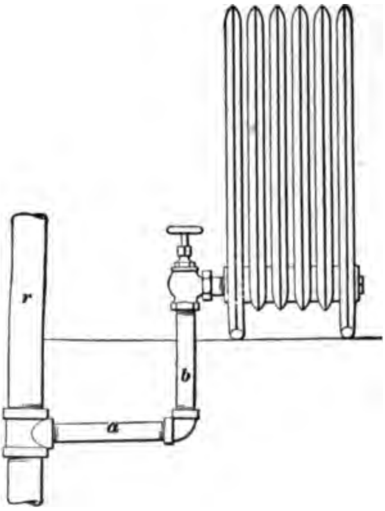

FIG. 697.

The drainage may be improved in some cases by connecting a drain pipe to the opposite end of the radiator, as shown in Fig. 698 at *d*. This pipe should be connected to the steam supply pipe at a higher level than the pipe *a*, but this arrangement is not to be recommended, because there is a liability of steam entering the radiator through *d*, and thereby forming a water hammer.

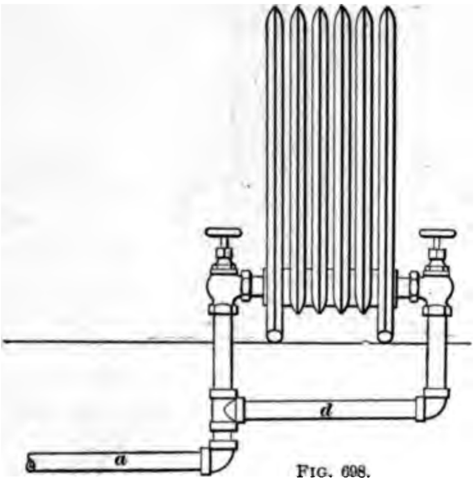

FIG. 698.

When the radiator is at a long distance from the riser, so that the drainage becomes difficult, it is advisable to put in a double connection, as shown in Fig. 699. The supply pipe *a* and the drain pipe *d* are both connected to the riser *r*, and a siphon is placed at *b*. All the water which flows through *a* will thus pass into the drain pipe without entering the radiator.

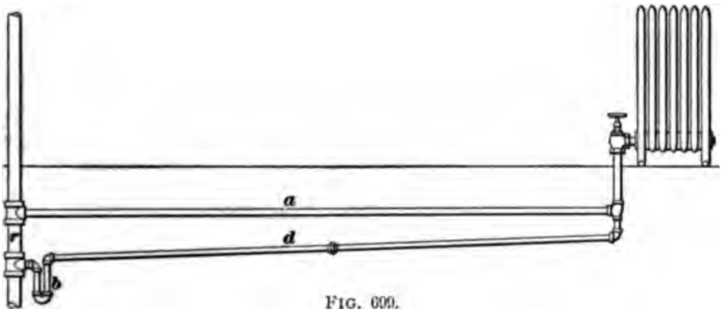

FIG. 699.

The connection shown in Fig. 700 permits the radiator to be set very close to the riser, and at the same time the spring piece *a* is so long and flexible that the riser may move considerably without causing any trouble. It also has the advantage of being entirely above the floor, so that it is accessible at all times, and the valve is brought out into a convenient position.

When the vertical movement of the riser is excessive, the swivel connection shown in Fig. 701 may be used. In this form of connection the pipe *a* may be inclined any amount desired, in order to secure perfect drainage.

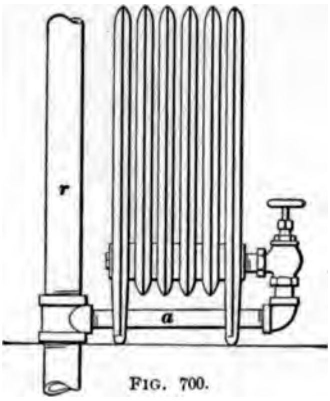

FIG. 700.

1742. Returns.—The downward grade given to return pipes should be uniform, as nearly as practicable. There should be no upward bends or loops, because air is likely to collect in them and impede the flow of water. Care must be also taken to avoid forming sags or depressions in which water will accumulate.

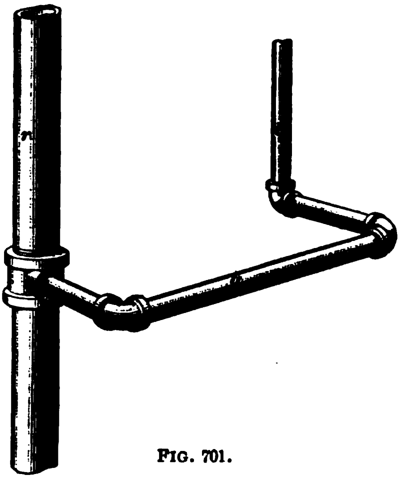

FIG. 701.

When the returns are connected to a main which is located above the water-level, the arrangement is called a **dry return.** If there is any perceptible difference in the pressures at the various radiators thus connected, the steam will flow backwards through the return pipes towards the points of lowest pressure, and in most cases will spoil the drainage and produce a water hammer. As the fall of pressure at any radiator is due solely to the resistance which the supply pipes offer to the flow of steam, it follows that the trouble in this case may be remedied by increasing the diameter of the supply pipes. It is quite impracticable, however, to connect drain pipes or returns leading from radiators having a considerable difference in pressure with a dry return main.

When the return main is located below the water-level, it is called a **wet return,** and the water which it contains acts as a barrier to prevent the passage of steam from one return to another. Thus the steam is compelled to pass through the system in the direction it was intended to go, instead of making a short-circuit or by-pass.

1743. Water-Level in the Returns.—There is always more or less difference in the pressure of the steam in the boiler and at the end of a line where the return is connected; therefore, the water will rise in the return to a height above the water-level in the boiler sufficient to balance the difference in pressure. As this difference varies in the several returns, the water is likely to stand at different heights in each. The hot water rises about 29 inches for each pound of difference in pressure. If there is a water pocket anywhere in the return pipe, the water will back up from it towards the radiator until it balances the difference in pressure upon the opposite sides of the water. Thus a radiator which is well above the proper water-line may be flooded with back water if there is a water pocket near it in the return.

SIZE OF PIPE REQUIRED.

1744. The proper size of pipe is one which will furnish a sufficient amount of steam without undue fall of pressure, and at the same time will not present an unnecessary amount of cooling surface.

It is found in practice, when steam having a pressure less than 5 pounds is employed, that the proper sizes for **branches** to radiators are about as follows:

TABLE 71.

BRANCHES TO RADIATORS.

One-Pipe System.

Heating Surface of Radiators.	Diameter of Pipe.
24 square feet or less	1 inch.
Above 24, not exceeding 60 square feet	1¼ inches.
Above 60, not exceeding 100 square feet	1½ inches.
Above 100 square feet	2 inches.

Two-Pipe System.

Heating Surface of Direct Radiators.	Steam.	Return.
48 square feet, or less	1 in.	¾ in.
Above 48, not exceeding 96 square feet	1¼ in.	1 in.
Above 96 square feet	1½ in.	1¼ in.
Heating Surface of Indirect Radiators.		
30 square feet or less	1 in.	¾ in.
From 30 to 50 square feet	1¼ in.	1 in.
From 50 to 100 square feet	1½ in.	1¼ in.
From 100 to 160 square feet	2 in.	1½ in.

1745. The size of **steam mains,** or of **principal risers,** may be computed by the following

Rule.—*Divide the amount of direct heating surface in square feet by 100; divide the quotient by .7854; then extract the square root of the quotient; the result will be the diameter of the pipe in inches.*

Example.—What diameter of main steam pipe is required to supply direct radiators having a total heating surface of 3,800 square feet?

Solution.— $\sqrt{\frac{3,800}{100} + .7854} = 6.9$ inches; or, in practice, 7-inch pipe. Ans.

1746. To find the amount of radiator surface which may be properly supplied by any given size of pipe, the reverse process should be followed.

Rule.—*Multiply the square of the diameter of the pipe in inches by .7854; then multiply the result by 100; the result is the total amount of heating surface, in square feet, which the pipe will supply.*

Example.—What amount of direct heating surface may be supplied by a steam pipe 7 inches in diameter?

Solution.— $7^2 \times .7854 \times 100 = 3,848$ square feet, nearly. Ans.

PIPING A BUILDING.

1747. New buildings are piped as soon as the walls are up and the roof is on, the ordinary constructional work being carried on as usual. On large jobs the risers are usually put up first, next the horizontal branches are constructed, proceeding always from the riser back towards the radiators, and lastly the mains are put in place. The returns are constructed at the same time and in a similar manner.

In many cases, however, particularly in small buildings, the mains are run in first, then the risers, and finally the radiator connections. This latter method avoids the use of "right and left" fittings, or unions, between the risers and the mains.

All radiator connections should be promptly **capped** as soon as erected, and all openings in T's and other fittings should be plugged at once, so that no dirt may get into the pipes.

1748. During erection, the question of **expansion** must be carefully considered. The best point at which to fasten each principal pipe so that its expansion will cause the least disturbance should be determined by close examination. Care must be taken to have every such pipe *free* at its ends, and to see that its connections or branches are not bound or rendered immovable by plaster, brick, wood, or iron beams or columns. The pipe-fitter should personally inspect every such point, and make sure that the pipe system is free to expand, before steam is turned on.

1749. The piping should be tested for tightness before it is covered by plaster or flooring, so that if any defective fittings or split pipes are discovered, they may be replaced without trouble. The **testing** is done by filling the system full of water, every opening being tightly closed, and then applying pressure by means of a force pump. The pressure is increased until the gauge shows from 100 to 150 pounds per square inch. A steam test should also be made, before the pipes are covered up, if possible. This will determine whether the expansion is properly provided for, and whether the system is in working order. The steam pressure used should not greatly exceed the proposed working pressure.

1750. All steam pipes should be kept out of contact with woodwork or other combustible materials. A clearance of at least two inches should be maintained at all points, and where this can not be done, special protection should be provided. Return pipes are liable at times to be filled with steam; therefore, they must be guarded the same as steam supply pipes.

Fig. 702 shows the manner of using **floor and ceiling flanges** to protect the woodwork where a steam pipe passes through an ordinary floor. When the ceiling flange *e* is secured to the pipe by a set-screw, as shown, allowance must be made in setting it for the vertical expansion of the pipe; otherwise, it will be liable to break the plaster forming the ceiling. A better construction is to connect the upper and lower flanges by a nipple a size or two larger than the riser, and have a current of air flowing through the spaces between the pipes and any combustible material.

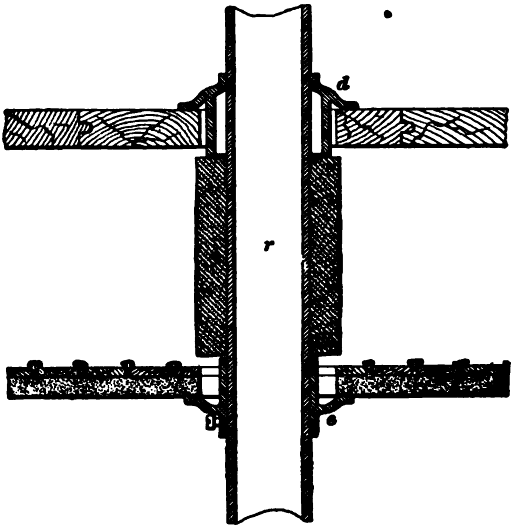

FIG. 702.

TYPES OF HEATING SYSTEMS.

1751. The various systems of steam heating now in vogue may be divided into four classes, according to the pressure of the steam and the manner in which it is used in them.

1752. The **high-pressure system** is operated with steam at any pressure above 10 pounds by the gauge, or thereabout. The radiators require less heating surface, and the piping may, in some cases, be made a size smaller than for pressures of 2 to 5 pounds. The fall of pressure that may be permitted at the radiators is, however, no greater than in a low-pressure system; therefore, the size of the piping can not be reduced to any considerable extent. This system requires a better class of steam generators, which are more costly than low-pressure generators, and the radiators also require to be made extra strong. High-pressure heating is seldom done, and is not to be recommended for domestic work.

1753. The **low-pressure system** is usually operated with pressures ranging from 2 to 5 pounds above the atmosphere. This system is most commonly employed, and is the one referred to throughout the text, unless otherwise stated.

1754. The **exhaust system** is in every respect a low-pressure system, except that it is provided with special apparatus which adapts it to receive the exhaust steam from engines and pumps. It is used only for the purpose of utilizing and saving the heat in exhaust steam which would otherwise go to waste.

The magnitude of this waste may be easily computed.

Assuming that the heat remaining in the condensed water can not be conveniently utilized, the quantities of heat stated in the steam tables may be reduced by 212 heat units. It will be seen that exhaust steam at 5 pounds (by the gauge) contains 971 units of available heat per pound, while live steam at 60 pounds pressure contains 995 units per pound—only 24 heat units more. Thus the exhaust steam in this case would contain 97½ per cent. of the available heat, and only 2½ per cent. would be used in driving the engines. The practice of allowing exhaust steam to escape into the atmosphere in any situation where it can be used in heating apparatus, either for house warming or heating liquids, etc., is, therefore, inexcusably wasteful.

The general arrangement of apparatus for controlling the steam supply and drainage in an exhaust system is shown in Fig. 703. The steam-heating main *a* is connected to the exhaust pipe *b* and also to a pipe *c* which supplies live steam from the boilers. This steam passes through a pressure-reducing valve *e*, and is lowered in pressure to the desired amount before entering the heating main. By this arrangement the heating system will be supplied with exhaust steam as long as the engines are in operation; but, if for any reason the supply becomes insufficient to maintain the proper pressure, then live steam will enter through the reducing valve and make up the deficiency. If the supply of exhaust steam

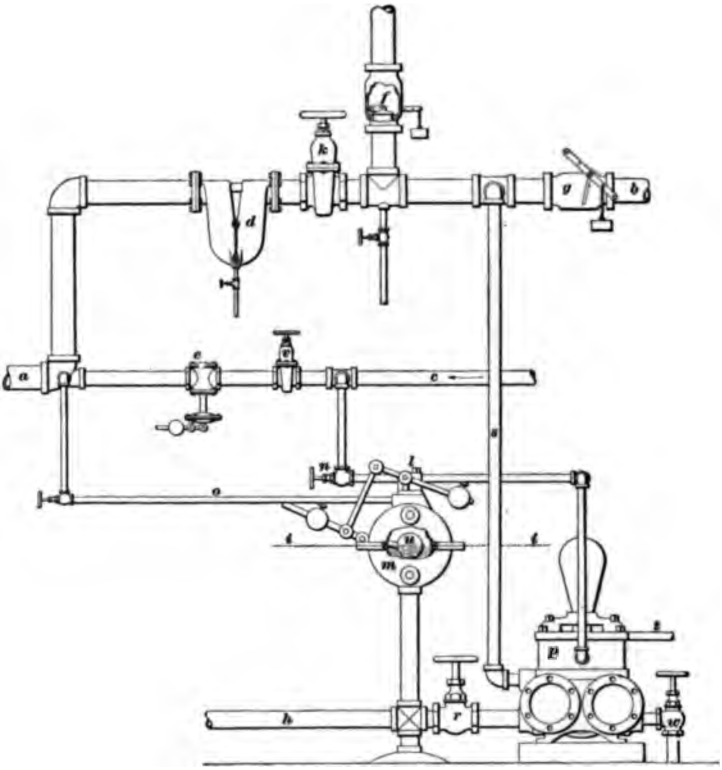

FIG. 708.

becomes so great that the pressure rises unduly, the excess will escape by opening the back-pressure valve *f* and blowing into the atmosphere. When the engines are stopped, the check-valve *g* prevents the steam in the heating apparatus from passing backwards and filling it up with water. This check-valve is similar in construction to the valve *f*, and is so nearly balanced by its counterweight that it will open very easily. The relief valve *f* is usually adjusted to blow off at a pressure about 1 pound higher than that maintained by the reducing valve *e*.

The exhaust steam is passed through a separator *d* before entering the heating system, for the purpose of removing the entrained water, and especially for removing the oil which accompanies it from the engine.

1755. The drainage from the heating apparatus is collected in the pipe *h* and is returned to the boiler by means of a pump *p*, as shown. The returns have no direct connection with the boiler; consequently, the water-level in them may be maintained at any convenient height, as at *i*, *i*. This is accomplished by means of the pump and its governor *m*. The **pump governor** is merely a closed vessel containing a float *u*, which rises and falls with the water-level. The steam which works the pump is taken from the high-pressure pipe *c* through the stop-valve *n*, and passes through the throttle valve *l*, this latter being controlled by the float. When the water rises above the desired level, the float opens the throttle and starts the pump; and when it subsides, the float sinks and shuts off the steam. The exhaust from the pump is turned into the exhaust main through the pipe *s*. The pump governor is connected by a small pipe *o* to the heating main *a* for the purpose of equalizing the pressure on top of the water contained therein.

Valves are provided in the main pipes at *k* and *v*, for the purpose of shutting off the heating apparatus during the summer season. It will be noted that these valves are located so that they do not interfere with the supply of steam to the pump, nor with the exhaust therefrom. The returns are shut off from the pump by the valve *r*, and an independent water supply is attached at *w*. The pump delivers through the pipe *t* to the boiler.

Care must be taken to locate the valves *f* and *g* properly with regard to each other, as shown in Fig. 703. If the check-valve is placed between the heating main *a* and the valve *f*, and the reducing valve *e* should get out of order, the pressure would rise in the heating system until it equaled that in the boiler. This would probably burst the radiators and do serious damage. The safety of the whole apparatus depends upon the good working condition of the relief valve *f*

1756. The **vacuum system** of steam heating differs from all others in one important particular, namely, that a vacuum, more or less perfect, is constantly maintained in the returns. This permits the system to be operated by steam of any convenient pressure, high or low, and from any source, either exhaust or otherwise. The pressure and temperature throughout the whole system may be adjusted and maintained at any point between full boiler pressure and a low vacuum, thus making the system adjustable to suit all conditions of weather and service.

Usually the system is operated with exhaust steam, the supply being arranged as shown in Fig. 703. The piping is usually arranged on the "two-pipe" system, and the returns are generally made independent, although it is not necessary to do so in all cases.

1757. Fig. 704 shows the essential features of the system. The returns *a* are connected to a receiver *b*, which collects all of the air and water in the system. These are pumped out by means of the **vacuum pump** *v*, which thus maintains a constant vacuum of any degree desired in the returns.

By this arrangement any steam may be used in the radiators that is warm enough to operate the traps. It permits steam to be used at a pressure far below the atmosphere, and at any temperature down to about 140°, the limit being fixed only by the ability of the pump to keep up the vacuum in the returns.

For the purpose of maintaining the vacuum there are various forms of exhausting apparatus which may be used in place of the pump, such as "ejector condensers," etc., but as they are not an essential part of this system, they will not be described here.

The water and air which are drawn from the receiver by the vacuum pump are discharged through *e* into an open tank *t*, from which the air readily escapes. The water is then pumped back into the boiler by any ordinary feed-pump, the suction pipe of which is shown at *f*.

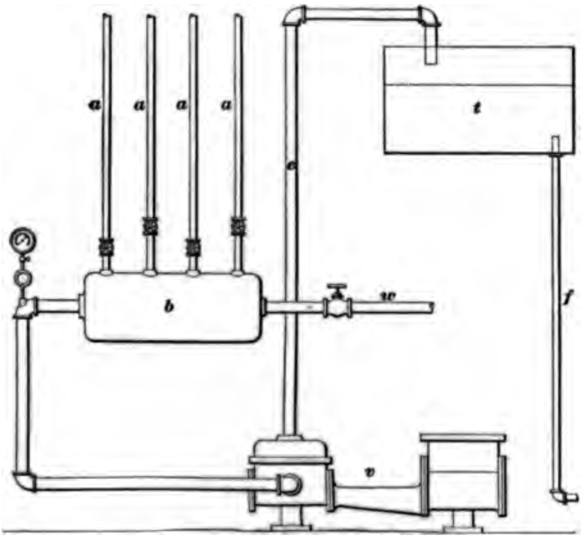

FIG. 704.

In some cases the fresh, cold water which is otherwise required to feed the boilers is injected through the pipe *w*
into the receiver in a series of fine ams, the object being
to condense as much as possible o eam which is pres-
ent, and thus improve the vacuu he same time that
the water is being warmed it give air accompanying
it, thus increasing the amount t ed by the pump.
This air expands into the vacu ially neutralizes

the effect of the condensation. Thus it will be seen that the introduction of the feed-water into the system at this point is of doubtful utility. If it is sent through an ordinary feed-water heater instead, it will become much hotter and the air will be eliminated without difficulty.

It will be understood that when the exhaust steam from an engine is turned into the ordinary low-pressure heating system, the back pressure is increased, and the efficiency of the engine is correspondingly decreased, sometimes to such an extent as to become very detrimental.

One of the principal advantages of the vacuum system is that a great part of the back pressure is taken off the engines, and their capacity to do useful work is thereby increased.

The size of the piping required for the vacuum system of steam heating is about the same as for the ordinary low-pressure system. The volume of the steam required is greater owing to the low pressure, and the amount of heat per cubic foot is correspondingly less than that found in ordinary heating systems, but the difference between the pressure of the steam in the supply pipes and in the returns is so great that the volume of steam necessary to carry the required amount of heat passes through the pipes without difficulty.

The radiators, however, must be larger than are used in any other system, proportionally to the decrease in the temperature of the steam used.

1758. The **district system** of steam heating is carried out in large towns and cities by means of steam mains which are laid underground through the streets. The arrangement of the connections from the street mains to the house pipes is shown in Fig. 705. The service pipe *a* is provided with a valve *b* inside the basement wall, so that the house system can be shut off when desired. The steam passes through a pressure-reducing valve *c*, and thence into the distributing pipe or house main *e*. Any water that may enter from the service pipe is led away by the drain pipe *d*.

The returns all connect with the pipe *f*, which is submerged below the water-level. The level of the water in the returns is fixed by the elevation given to the steam trap *t*; it is at the line *g* in the figure. The hot water from the trap should never be discharged directly into the house drains, because of its destructive effect upon the pipes, but should be cooled before escaping to the sewers, by first allowing it to flow through a coil of pipes. This coil is usually called a "cooling coil." It should never deliver directly into the drainage system, but in all cases should deliver into a deep, sealed trap. This is to prevent drain air from entering the heating system or the building. The trap, or hotwell, should always deliver into the house sewer connection on the sewer side of the main drain trap, so as to prevent hot vapors from passing up the iron drainage system in the building.

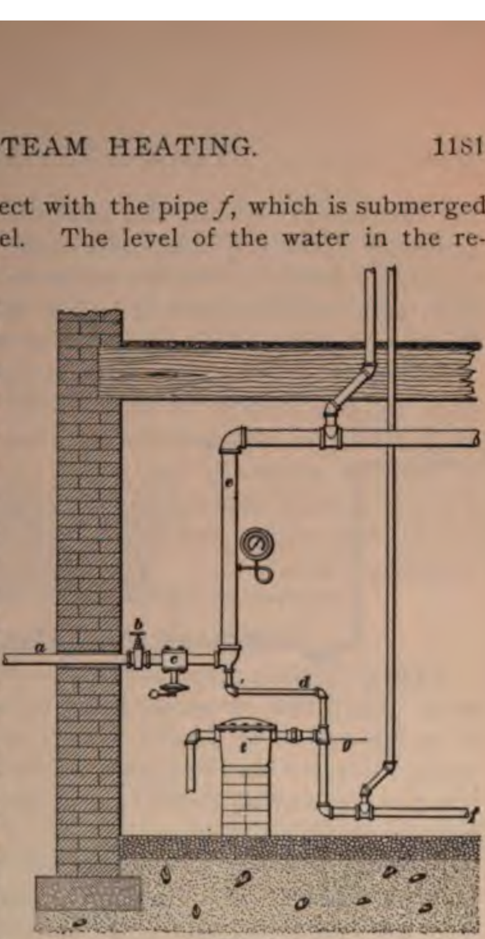

FIG. 705.

INDIRECT STEAM HEATING.

1759. The piping for indirect steam heating, or for the direct-indirect method, must be arranged on the same principles as for direct heating. In many cases the pipes must be made somewhat larger, because the radiators emit more heat and condense more steam per square foot of surface. Drainage is of the utmost importance, because the movement of air through the apparatus depends primarily upon the temperature of the radiators. The apparatus may be operated with steam of high or low pressure, with exhaust steam, or by the vacuum system, as may be most convenient in each particular case.

The mode of driving the air through the apparatus and flues, for the purpose of distributing the heat throughout the building, is substantially the same whether the heating is done by steam, by hot water, or by hot-air furnaces. The problems of moving and distributing air belong properly to the art of ventilation, and need not be further considered here.

COOKING APPARATUS.

1760. Cooking operations are performed by steam in three ways: *first*, by suspending the material to be cooked in an atmosphere of steam; *second*, by heating in kettles or ovens which are provided with external steam jackets, and, *third*, by immersing steam coils in the water or other liquid which is to be boiled.

In the first method the steam comes into direct contact with the material and permeates it, thoroughly heating every part and converting the water contained in it into vapor. When the material is removed, much of the vapor contained in it disperses into the surrounding atmosphere, leaving it in a warm, half-dry condition. This method is very desirable for cooking many articles of food.

1761. The construction of an ordinary **cooking box** is shown in Fig. 706. It consists of an iron box *a* having a deep groove around its upper edge filled with water. The cover *b* is provided with a deep flange which dips into the water in the groove and thus forms a water seal. Steam is admitted at about atmospheric pressure by the valve *c*, and the air is blown out through the valve *d*. The food to be cooked is contained in wire baskets, etc., which are placed upon a perforated plate *f*. The condensed water collects in the bottom and runs off through the trap *e*. This trap must not be connected to the sewer pipes, but should empty into a sink or some clean place which is not exposed to foul air.

Cooking boxes are also made with hollow sides and bottom, steam being admitted only to the space between the inner and outer walls. The cover is made with a water seal, and the inner chamber is provided with a vapor pipe which permits the steam and odors arising from the food to escape. When it is desired to confine the steam in order to retain the flavor of the food, the vapor pipe is provided with a trap.

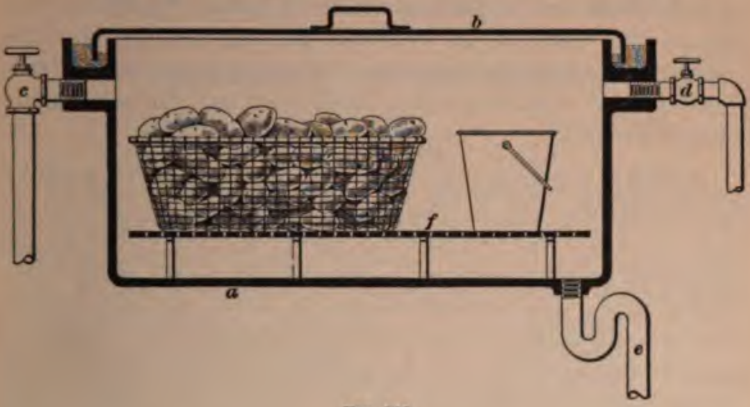

FIG. 706.

The cooking apparatus designed for family and hotel use usually has both kinds of boxes combined in one frame, and frequently includes a steam-heated oven.

1762. Ovens require a temperature of 250° to 300°; consequently, only high-pressure steam can be used to operate them. They are sometimes constructed with double walls, the steam being admitted between them, but a more common method is to heat them by means of steam coils placed in the interior of the baking chamber. It is essential that the circulation in the coils be positive and rapid, and also that they be thoroughly drained.

All the different varieties of ovens must be provided with suitable vents by which the vapors generated by the baking process may escape. The vapor from japanning ovens is explosive when mixed with air; therefore, it must be discharged in some place not exposed to fire or gas lights.

1763. Steam-jacketed kettles are extensively used for cooking on a large scale, for manufacturing candy, glue, sugar, and for many other purposes. The advantage of the steam kettle over apparatus which is heated by fire is that the heat is uniform all over the heating surface, and the temperature may be maintained at any degree desired, from 100° to 300° or more without variation, and for almost any length of time.

1764. Cooking is also done in large **tanks** or **vats** by placing steam coils in the liquid near the bottom. These coils should never rest directly upon the bottom, but should be raised up a few inches to permit the liquid to circulate below them. The pipe should not be coiled closely together, but enough space should be left between the convolutions to permit the liquid to circulate readily between them. The condensation in these coils is very great, and to ensure successful operation, particular care must be taken to drain them thoroughly. In many cases it is necessary to remove the coils frequently for the purpose of removing sediment, etc., from the vats; consequently, in such cases the connections should be so arranged that the coils can be disconnected with little loss of time or labor.

HOT-WATER HEATING.

HEATING APPARATUS.

BOILERS.

1765. The boilers used in hot-water heating systems are similar in all respects to the best forms of steam boilers, except that the spaces commonly reserved for steam room may be dispensed with, or be utilized for tubes and other heating surfaces. Thus, in a **common tubular boiler** the entire shell may be filled with tubes, as shown in Fig. 707.

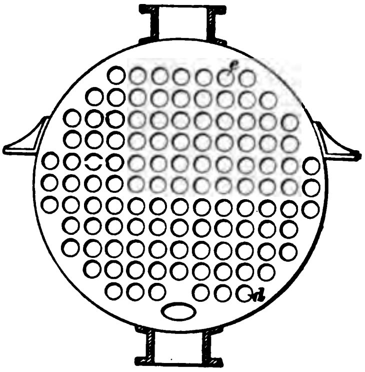

FIG. 707.

The circulation inside of a hot-water boiler is quite different, however, and in many parts is probably much slower than in a steam boiler. The cold water enters at the bottom, and, when heated, passes out at the top; the general movement is, therefore, upwards, and there is only a moderate amount of return, or local, circulation within the boiler. The local convection currents move comparatively slowly because the difference in weight of the ascending and descending particles is necessarily small, the actual working height of such local circuits seldom exceeding two or three feet.

The water should pass from the inlet, over the heating surfaces, and on to the outlet in the most direct manner and with the least possible resistance.

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1766. The various **aids to circulation** which are generally used in steam boilers, and which serve excellently for steam making, are of little or no value in a hot-water boiler. Thus, circulating tubes can rarely be used to any advantage; and drop tubes, which add so largely to the capacity of a steam boiler, have no advantages for heating water, because there is no practicable method for maintaining a rapid circulation through them. In a steam boiler the depth of water is comparatively small, and the circulation is greatly increased by the formation of multitudes of steam bubbles which mix with the ascending water and make it much lighter than an equal volume of the descending current.

The heating surfaces in a hot-water boiler are usually 40 to 60 feet, or more, below the surface of the water, and the formation of steam bubbles upon the surfaces is not desirable, because it is likely to be accompanied by loud rumblings and snapping noises. The bubbles of steam condense upon coming into contact with the colder parts of the water, and the result is "water hammer." If the steam could be confined to the water passing up the main riser, it would greatly increase the motive force of the general circulation, by decreasing the mean density of the fluid in the rising part of the system, thus diminishing the resistance to the flow of cooler water in the returns. This scheme, however, seems impracticable.

1767. The **area of heating surface** required in a hot-water boiler for any given transmission of heat is the same as in a steam boiler working at the same temperatures of water and combustion. The required areas of grates and chimney are also about the same.

1768. The numerous varieties of hot-water boilers now on the market differ greatly in the **volume of water** which they contain, although they may have equal heating power. A heating system which contains only a small amount of water can be heated quickly, but it will also cool quickly; whereas, if the volume of water is large, it will act as a reservoir of heat and so maintain a moderate temperature for a considerable time after the fire has dropped.

DESCRIPTION OF BOILERS.

1769. The common return tubular boiler shown in Figs. 636 and 637, Arts. **1640** and **1641**, is extensively used for hot-water service. The number of tubes, however, is usually increased, as shown in Fig. 707, and the setting is sometimes modified, as in Fig. 708. The brickwork is arched over the top of the shell, and the hot gases of combustion are permitted to pass all around the boiler before they enter the tubes at the rear end. The riser *A* and return pipe *B* are made conical where they join the shell, to facilitate the flow of the water as much as possible. Care must be taken in locating the upper and lower rows of tubes, *c* and *d*, in Fig. 707, to avoid obstructing the inlet and outlet connections.

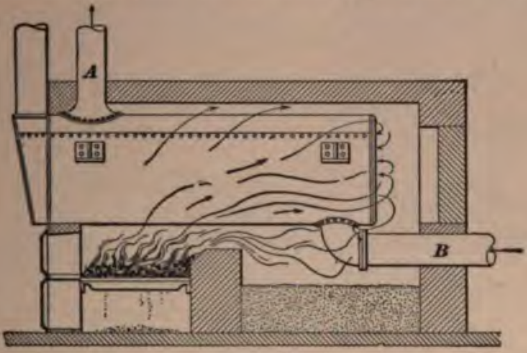

FIG. 708.

Several other boilers, previously illustrated, are commonly used for hot-water service; for example, Figs. 639, 640, 644, 645, and 647. Figs. 639 and 644 are especially adapted for "combination" service, that is, to be used as a hot-water boiler during moderate weather, and as a steam boiler in severe weather.

1770. An improved variety of **cast-iron sectional hot-water boiler** is shown in Figs. 709 and 710, the latter figure showing the interior construction and arrangement of parts. The several sections are united by packed joints at *a* and *b*, and are clamped together by bolts at *d* and *e*. The furnace is "internal," and even the ash pit is surrounded with water. The hot gases pass to the rear section and then to the front end through the flues *g*, returning to the smoke-stack *k* through the upper flues *h*. The boiler rests upon a base block *c*, which maintains it in a proper position. The main pipes are connected by risers *f* to the top of the boiler, as shown.

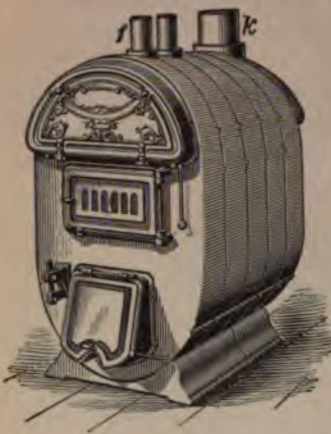

FIG. 709.

1771. Fig. 711 shows a **greenhouse boiler.** The characteristic feature of this class of boilers is that they are made as low as possible, in order to adapt them to the very small hydraulic heads commonly found in greenhouse work. In some cases the head does not exceed one foot, and the boiler must, therefore, be designed to offer the least possible resistance to circulation. The sides and top of the fire-box

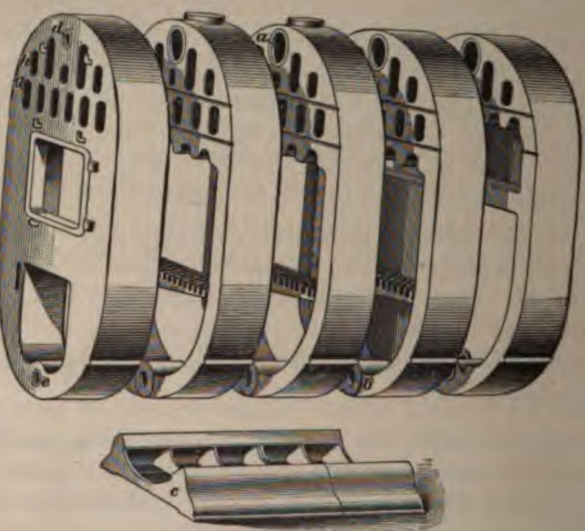

FIG. 710

are corrugated, to secure the maximum of heating surface. The water enters the leg of the boiler at *a* and passes out at *b*. The hot gases of combustion are spread out over large heating surfaces, and have ample time to impart their heat to the water before escaping to the chimney.

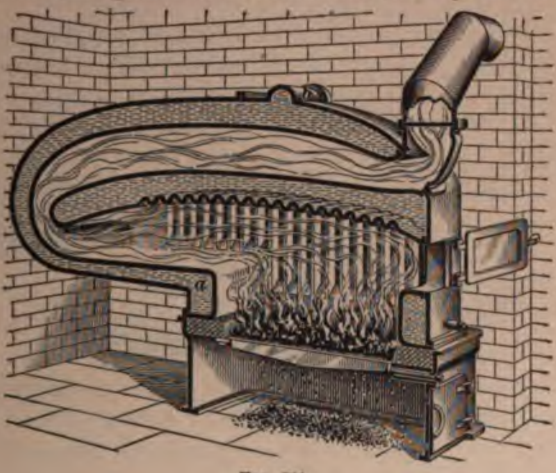

FIG. 711.

1772. High-pressure boilers are used for heating with hot water, having a high temperature and correspondingly high pressure. They are usually constructed of tubing, essentially as shown in Fig. 712. The furnace chamber is enclosed on the sides with firebrick, and on the top with tubes which form a box coil. The tubing is of wrought iron or soft steel, about $\frac{7}{32}$ inch thick, and the bore is usually $\frac{3}{4}$ or 1 inch. All the joints on the boiler or heating coils are welded.

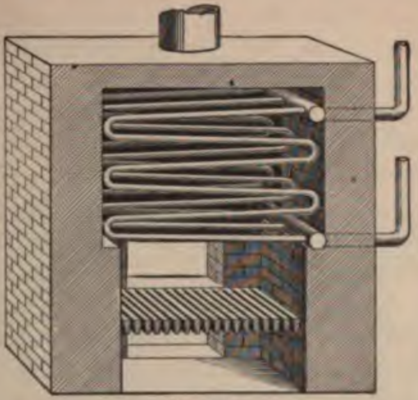

FIG. 712.

Any approved water-tube boiler which is designed for a working pressure of 150 pounds per square inch is equally serviceable, however, and may be employed, in place of the above, to good advantage.

Cast iron is not a suitable material for high-pressure boilers, especially if there are any flat surfaces. In all cases, wrought iron or steel should be used, and the surfaces should also be round. The pipe, or cylindrical form, is always preferable for strength.

High-pressure heaters ought never to contain a large volume of water, because the danger from an explosion would in that case be too great.

DRAFT REGULATORS.

1773. It is more difficult to automatically regulate the draft in a hot-water heater than in a steam boiler. In the latter case the regulator is operated by the *pressure* of the steam, and this pressure is nearly the same in all the pipes which lead from the boiler. In a hot-water apparatus, however, only the *temperature* varies to any considerable degree, but it does not vary to the same extent in the several risers, or mains, that are connected to the heater. Thus there may be an active circulation in one riser, while there is little or none in the others, owing to the radiators being out of use, etc. If the draft regulator is connected to any pipe which does not take the whole flow, it will be governed by the temperature prevailing in that particular part of the system, instead of by the average temperature of the entire system. The best method in such cases is to construct a short direct circuit especially for the regulator. The temperature in this circuit will correspond very nearly to the average temperature of the water in the boiler.

Draft regulators are constructed to operate in many different ways. Some depend upon the changes which occur in the length of a pipe caused by variations in the temperature of the water passing through it. This movement is so small, however, that the apparatus is necessarily delicate.

1774. A more practicable method is to utilize the expansive force of some volatile liquid which is acted upon by the hot water passing through the apparatus. A regulator of this kind is shown in Fig. 713.

It contains a diaphragm of ordinary construction, surmounted by a stem *i*, which operates the lever *d*, which is loaded with a weight *w* and pivoted on a fulcrum *e* in the usual manner. A large corrugated brass cup *g*, having an aperture at the bottom only, is attached to the under side of the diaphragm. The space between the cup and the bowl is filled through *f* with some liquid more volatile than water, usually a mixture of water and alcohol. The cup is filled only with air or vapor. Hot water from the heater enters the chamber *c* through *a* and returns to the heater through *b*, as shown by the arrows. This water heats the liquid and vapor in the bowl and cup. The pressure generated is proportional to the temperature of the water, and is sufficient to properly operate the diaphragm and the apparatus attached to it.

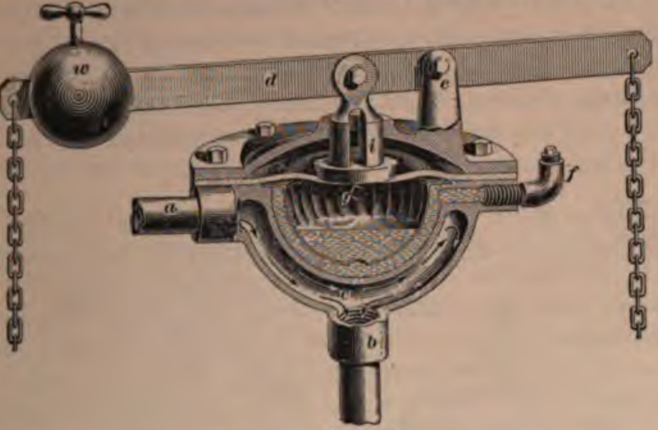

FIG. 713.

EXPANSION TANKS.

1775. The purpose of an expansion tank is to keep the pipes and other apparatus constantly full of water. The water in the heating system expands when heated, and if it fills the apparatus when cold, it will overflow when hot, and the expansion tank serves to receive this overflow.

The capacity of the tank required in any given case depends upon the volume of water in the heating system and the highest temperature which it will attain. In an ordinary system, where the tank is open to the atmosphere, commonly called the low-pressure, or **open-tank,** system, the temperature can not be raised much above 212°. By referring to Table 51, Art. **1359,** it will be seen that water expands .044, or about $\frac{1}{20}$, of its original volume by being heated from 32° to 212°; consequently, the capacity of the expansion tank, between high and low water marks, should be about $\frac{1}{20}$ of the total contents of the apparatus to which it is attached.

1776. When the water is to be heated to a higher temperature, as in the so-called high-pressure, or **closed-tank,** system, the expansion tank must be closed and its capacity must be greatly increased. Not only must space be provided for the expansion of the water, but there must be additional space above the water when the latter is expanded to its utmost, sufficient to contain the air which originally filled the tank, without compressing it too much. The pressure of the air thus compressed should not exceed the pressure of steam corresponding to the maximum temperature of the water, as indicated in the steam tables.

For example, if the water is heated to 350°, it will expand about .12, or $\frac{1}{8}$ of its original volume, and the tank must have a capacity between high and low water marks equal to $\frac{1}{8}$ of the total contents of the apparatus, including pipes, radiators, and boiler. Having computed the actual volume required for the expansion of the water, the additional space for air may be readily found. The pressure of steam having a temperature of 350° is about 135 pounds, absolute. Air must be compressed to about $\frac{1}{9}$ of its original volume to produce that pressure; therefore, the space for air, above high-water mark, should be $\frac{1}{9}$ of that allowed for expansion.

1777. Safety Valves.—In practice, any *closed* hot-water system is liable to be neglected and overheated. The expansive force of the water is practically irresistible, and if there is not sufficient room for it to expand, it will burst the apparatus. The only mode of securing safety is to provide the closed tank with a safety valve. This may be set to blow off at the pressure which steam would have at the maximum temperature desired in the apparatus. No closed tank should ever be worked without a safety valve.

A hot-water apparatus having an *open* tank is absolutely safe from accident by bursting so long as open communication exists between the tank and boiler. But if the tank is closed for any reason, or its connections are closed, it is thereby converted into a dangerous apparatus.

1778. Freezing.—The connection of the tank to the heating apparatus must be carefully protected against frost. When this connection is frozen, the apparatus is deprived of the relief afforded by the tank, and a rupture is sure to occur in some weak part when the water is being heated.

1779. Stop-Valves.—Open communication between the expansion tank and the boiler must be maintained at all times. No stop-valve should ever be placed on this pipe, and wherever one is found it should be removed. Such a valve is liable to be closed, and thus cause disaster.

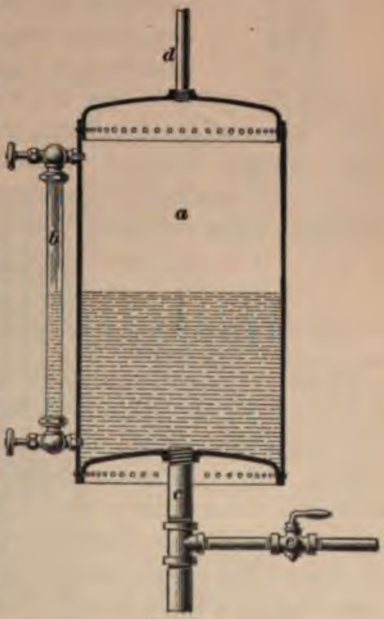

FIG. 714.

An ordinary **low-pressure expansion tank** of this construction is shown in Fig. 714. The body *a* and the heads are made of wrought iron, and should be galvanized inside and out. A glass water gauge *b* marks the height of the water inside. The surface of the water should be visible in the gauge both at its lowest and highest levels. The tank is connected to the heating apparatus by an **expansion pipe** *c*. A connection to the cold-water house-supply pipe may be made at *e*, for convenience in filling the tank. The top of the tank is always open to the atmosphere through the pipe *d*. *This opening must never be closed.*

1780. An expansion tank suitable for high pressures is shown in Fig. 715. It differs from that shown in Fig. 714 mainly in its proportions, being of smaller diameter in proportion to its length, and it is also made of much thicker material. The outlet pipe is controlled by a safety valve *a*. The height of water is shown by the gauge or "try" cocks *b*, *c*, *d*. Glass water gauges are not suitable for high-pressure tanks, because they are very liable to crack and burst, and thus allow the water to escape and damage the building.

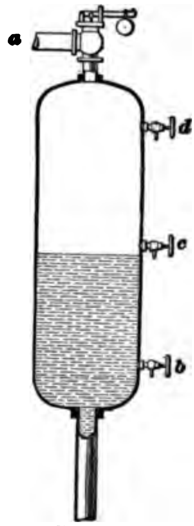

FIG. 715.

COMPENSATING APPARATUS.

1781. Other methods besides expansion tanks are used to provide for the expansion of the water and also to keep the apparatus properly filled. In an ordinary low-pressure system, the apparatus may be closed at the top, and connected at the bottom to the cold-water pipe of the plumbing system, in the same manner as the ordinary kitchen boiler. Of course, this should not be done unless the pressure in the street mains is high enough at all times to raise the water to the top of the building. When the apparatus is fired up, the excess of water resulting from expansion will drive back into the street mains. A safety valve must always be provided, however, to prevent over-pressure in case the connection to the street main is shut off or is frozen. A check-valve may be placed in the supply pipe to the boiler, so that the apparatus can not lose any of its water by a fall of pressure in the street mains.

High-pressure heating apparatus may be arranged in a similar manner. The expansion tank is omitted, and a double valve, constructed about as shown in Fig. 716, is used instead. An ordinary valve *a* which is held down on its seat by a dead weight *w*, secured to the valve stem, permits the escape of the excess of water resulting from expansion. The ordinary check-valve *b* permits fresh water to enter and keep the pipes full when the apparatus cools off. The pipe *c* extends to any convenient source of supply.

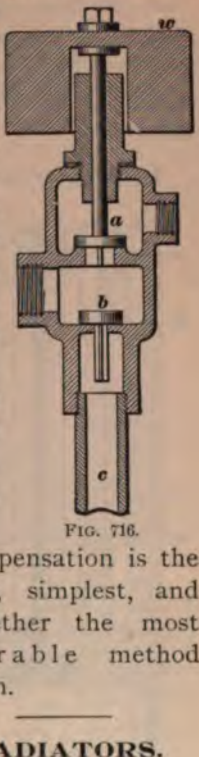

FIG. 716.

The open expansion tank method of compensation is the safest, simplest, and altogether the most desirable method known.

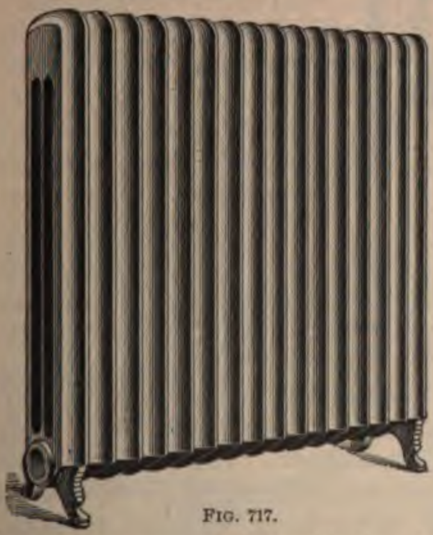

FIG. 717.

RADIATORS.

1782. Radiators for hot-water heating should be composed of vertical tubes, and these must be connected with ample waterways at both top and bottom. The continuous **pipe coil,** which is so effective in steam heating, has few advantages when applied to hot-water heating, and is quite inferior to the vertical loop radiator shown in Fig. 717.

The circulation in a coil will gradually stop as air collects in the upper pipes, or header, but it will continue in a vertical loop radiator as long as the level of the water is above the line *a* in Fig. 718. If it falls, say to the line *b*, the hot water will diffuse slowly up each side of the loop, while the main circulation passes directly from the inlet to the outlet.

1783. The **connections** of the loops to each other at the bottom should be more than equal in area to the supply pipe; otherwise, the resistance will be so great as to seriously impede the main circulation.

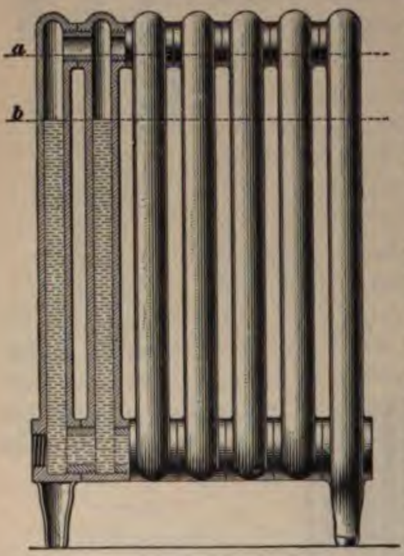

FIG. 718.

1784. Hot-water radiators are often made with **three tubes** in each loop instead of two, and it is supposed that the water will ascend in the central tube and descend in the side tubes. There is, however, no appreciable difference in operation between the three-tube loops and those having only two tubes.

1785. Hot-water radiators must have **two connections,** one for the inlet and the other for the outlet. They can not be operated successfully with a single connection. The supply may enter the top or bottom of the radiator, but the outlet should connect to the bottom.

In using hot-water radiators for indirect heating, particular care must be taken to prevent them from being frozen by circulation being shut off. The best preventive is simply to connect such radiators direct to the system without any controlling valves being attached to them. This will ensure a constant circulation while a fire remains in the boiler.

FITTINGS, VALVES, AND VENTS.

SPECIAL FITTINGS.

1786. The fittings ordinarily employed in steam piping are objectionable for hot-water heating apparatus, because of the great resistance which they offer to the flow of water, due to the angles being too abrupt. The enlargements commonly made in pipe fittings are of little consequence when steam flows through them, but they retard the flow of water too much in a hot-water heating system, because the motive force of the current is so small in proportion to the amount of resistance offered. Elbows for hot-water service should be made with a radius equal to five times the internal diameter of the pipe, as shown in Fig. 719. Such elbows are generally made of wrought iron or steel pipe, bent to shape, and are, consequently, usually called **bends.**

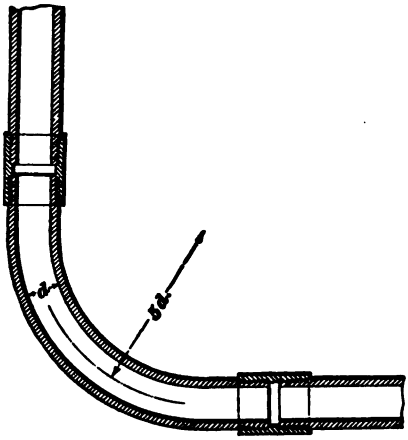

FIG. 719.

When common pipe fittings must be employed, the evil may be mitigated somewhat by carefully reaming out the ends of the pipe, as shown in Fig. 720.

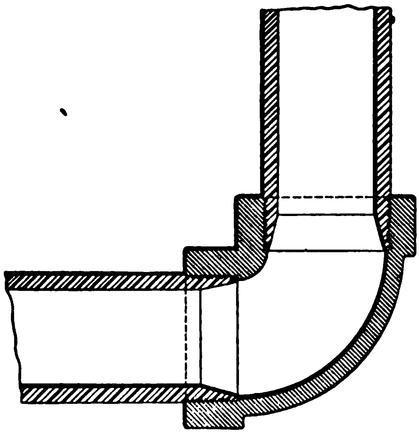

FIG. 720.

The common screw

union should never be used in hot-water piping; the right and left coupling should always be employed instead. In large pipes, only the flanged unions should be used.

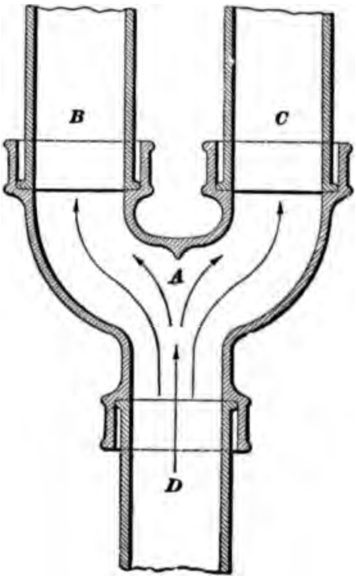

FIG. 721.

1787. The fittings for cast-iron pipe such as those used in greenhouse heating should always be of the variety known as **flush** fittings; i. e., they should have the same internal diameter as the pipes to which they are attached, as shown in Fig. 721. Fittings having internal beads or shoulders, and an enlarged bore, should be discarded, as they offer too much resistance.

1788. Fig. 722 shows a group of special fittings, some of which are well adapted for hot-water heating, and others are not. The fitting *A* has large round corners between the branches *a*, *b*, *c*, making it superior to the common **T**, but it is not desirable for hot-water heating. It was designed originally for cold-water piping, where the water is required to flow either way, as the demand for water may require. In hot-water heating the direction of the currents is always the same, and the purpose can be accomplished with less resistance by using the **twin elbow** *B*. This may be used to divide a main current *c* into two branches, or to combine two currents, *a* and *b*, into one main. If the fitting *A* is used for the latter purpose, there will be a great resistance caused by the conflict of the opposing currents *a* and *b*.

When a branch is to be taken off a main line or is to be united thereto at right angles, the fitting *C* should be used instead of a common **T**, the curves of the branch being turned in the direction of the flow. The fitting *E* also serves the same purpose when the angle of the branch is 45° instead of 90°.

The double-branched fittings *D* and *F*, however, are not desirable for hot-water service. The motive force of the water is so small that a slight difference in the resistance of one of the branch circuits may cause one branch to rob the other to a serious extent. Similarly, when two return currents are connected into the same fitting on a main, a small preponderance in one circuit will often cause the flow in one branch to nearly block the opposite one. A safer way is to connect each branch separately.

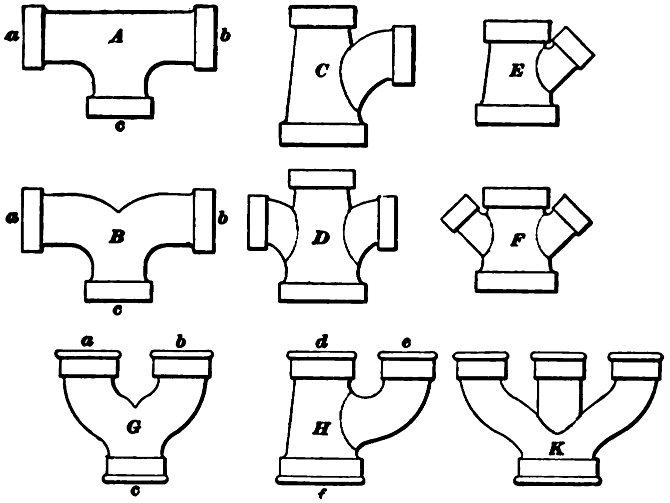

FIG. 722.

The fittings *G*, *H*, and *K* are designed especially for greenhouse heating. *G* is used to divide a main current into two equal but smaller currents without changing the direction, or for uniting two currents into one. *K* serves for dividing the main current into three equal currents. The fitting *H* is used in a manner similar to *G*, but usually for the special purpose of creating a greater resistance in the branch *c* than in *d*. This is necessary sometimes, when the branch circuits are of unequal length or resistance.

1789. Fig. 723 shows a fitting designed for connecting a radiator to the supply main, in a single-pipe hot-water heating system. The flow pipe to the radiator is connected into the vertical branch *b*, and the return pipe is connected into *c*. This branch encircles the body of the fitting and opens into it only upon the under side. The hot water in the main is supposed to pass up through *b* to the radiator, while the cooler return water flows back into the lower side of the main, the circulation through the radiator being purely local. It is designed to take the place of the fittings shown in Fig. 729.

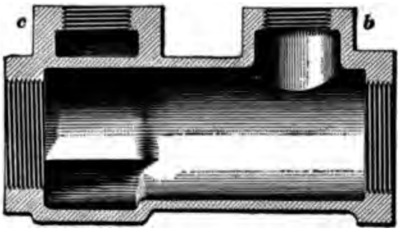

FIG. 723.

1790. Another special fitting, shown in Fig. 678, Art. **1716,** is well adapted for hot-water service. It is used in the lateral branches of flow pipes in place of an ordinary **T**. The momentum of the rising current is utilized to drive water into the branch, and the rising pipe is prevented from taking an undue share. It will be found especially useful in cases where the branch circuit is long and sluggish. It serves the same purpose as the offset in the riser, which is shown in Fig. 679, Art. **1716.**

VALVES.

1791. The requirements of valves used in hot-water heating apparatus are very different from those met with in steam heating or in ordinary plumbing. In the latter cases the valves must close with sufficient force to be tight against considerable pressure, but in hot-water heating they require only to check or direct a current of water having but a very small propelling force. The stems must be packed with equal care, however, to prevent leakage, and the valve bodies must be equally strong to resist static pressure and rough usage; but the valve proper, i. e., the part which serves to shut the passage, may be of very light construction.

1792. Globe valves offer so much resistance to the passage of water that they should not be employed in hot-water apparatus at any point. The common **angle valve** offers more resistance than it ought, but is tolerated mainly for want of something better. It may be used as a radiator valve, but it should never be used in main line piping, because the turn is much too abrupt.

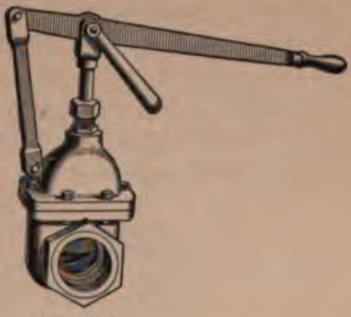

FIG. 724.

1793. Gate valves should be used exclusively in all the piping of a hot-water system. The heavy internal construction employed in steam valves may be dispensed with. A light single gate is sufficient, and the powerful operating screw which is required for steam or water may even be replaced by the light sliding stem and lever, as shown in Fig. 724. These lever valves have advantages over valves operated by a wheel and screw, in that the position of the lever always indicates whether the valve is closed or open, and there is never any uncertainty about the proper mode of operating the valve.

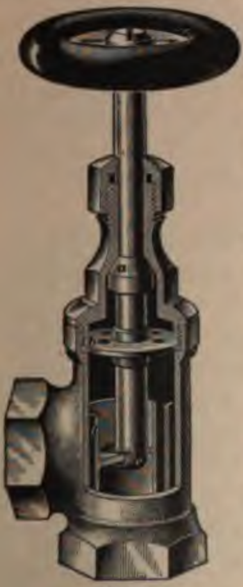

FIG. 725.

1794. A special **radiator valve** is shown in Fig. 725. The valve *d* is a light semi-cylindrical shell which covers the outlet port. It opens by turning the spindle part way around. The attachment to the spindle *c* is made midway in the length of the valve, so that it opens without any tendency to twist. The spring washer *b* acts as a guide for the valve, and serves to force the conical valve *a* against its seat in the cap, and thus prevent leakage around the stem.

1795. To prevent the water in a radiator from freezing when the radiator is not in use, it is a common practice to have a small hole (about $\frac{1}{8}$ inch in diameter) through the valve, so that a slight circulation will always be maintained in the radiator when the valve is shut. This **by-pass** to the valve is intended to furnish enough circulation to prevent the temperature of the radiator from reaching 32° F. when the air is near zero.

The size of the by-pass must be proportional to the size of the radiator, but in very few cases does it require to be more than $\frac{1}{4}$ inch in diameter.

Many radiator valves have been designed for hot water service, on the general plan of a plug-cock, but they are usually so bulky as to be undesirable.

1796. The **butterfly valve,** shown in Fig. 726, is sometimes used in large pipes for the purpose of regulating the flow at certain points, and thus increasing the circulation through such branch circuits as would otherwise be too sluggish.

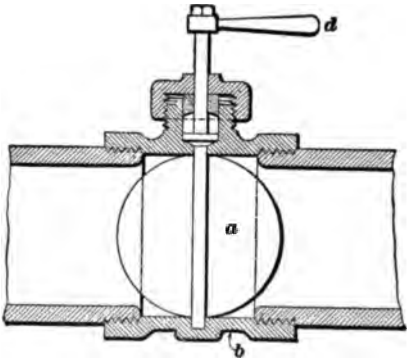

FIG. 726.

It consists of a metal disk *a* of the same diameter as the body or shell *b*, and having a lever handle *d* by which it may be turned crossways of the pipe to any degree desired. The diameter of the disk is obviously limited by the size of the opening at the end of the shell; and the obstruction caused by the disk when standing edgeways to the current is usually compensated for by the increased diameter of the passway.

AIR VENTS.

1797. Any kind of small valve or pet-cock will serve as an air vent for hand regulation; but there are many situations where the venting must be performed automatically. In **automatic vents** the escape valve must be controlled by a **float,** so that it will remain closed as long as water is present, and will open only when the water is displaced by air. Air vents for steam heating are frequently constructed with a float which serves to close the vent and prevent the escape of water, but the float in a hot-water air vent operates in a very different manner. The buoyancy of the float, when surrounded by water, is, depended upon primarily to close the valve; therefore, it should be constructed in such a way that it can never fail to be buoyant. This can be done only by closing the float at both ends, making it perfectly air-tight.

The air which is trapped in any part of a hot-water system has the same pressure as the water, and tends to hold the valve against its seat in the same way that any check-valve is held shut. Therefore, the weight of the valve and float, *when surrounded by air only*, must be sufficient to pull the valve open against the internal pressure.

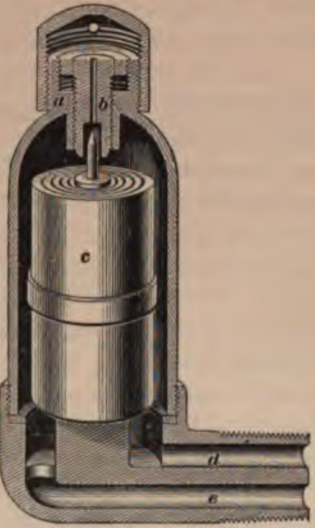

FIG. 727.

An air vent of good design is shown in Fig. 727. The float *c* is air-tight, and the valve seat is made in the screw *b*, which is adjustable in the neck *a*. There are two inlet openings, *d* and *e*, so that the movements of the air and water in entering or leaving the float chamber can not interfere at any time.

The changes which occur in the temperature of the water in hot-water heating apparatus can not be utilized to control the air vents.

PIPING.

SAGS AND AIR POCKETS.

1798. Water at ordinary temperatures, if exposed to the air, is always charged with a certain amount of air and other gases which it seems to hold in solution. Distilled water, for example, when exposed to the atmosphere, will absorb about 4 per cent. of its own volume of air, and if placed in an atmosphere of carbonic acid gas, it will absorb 100 per cent. of its own volume.

When water so charged with air or other gases is increased in temperature, the gases are gradually evolved from the liquid and rise in small bubbles to the surface until the water has reached the boiling point, when all the air will be liberated and steam will form. Now, it will readily be seen that when fire is first started in a hot-water boiler, air will be liberated from the water and will rise to the highest points of the heating apparatus, where it will accumulate and form **air locks** if it can not escape into the atmosphere.

This matter must be carefully looked after in constructing hot-water heating apparatus, because the motive force is so small that it may be easily neutralized and the circulation stopped by an air lock of comparatively small size. Air always collects in all high places, such as the tops of radiators, the upper ends of vertical pipes, etc., and these points should always be provided with air vents.

1799. All horizontal supply or **flow** pipes should be inclined upwards upon a uniform grade, so that the air will readily flow into the risers. The air in the pipes will then pass up into the expansion tank and escape into the atmosphere or into the radiators. If this can not be done, an automatic air vent of sufficient capacity must be attached to the piping at the highest point.

In many cases air pockets may be vented advantageously by attaching a small pipe to the top of the pocket, and extending it to the top of the house, at least as high as the top of the expansion tank, leaving it open to the atmosphere, preferably over the expansion tank. This makes a reliable vent, but the special pipe can not always be permitted. Care must be taken to keep it from freezing, because there is no circulation through it.

A bubble of air lodged in a pipe will obstruct the flow of water through it, to the same extent as a block of wood or metal of the same size. Thus, in Fig. 728, if the bubble *a* occupies two-thirds of the area of the pipe, the remaining third only is available for the passage of water. Although the air is very elastic and light, yet it occupies space just as positively as any solid substance.

The bubble can be dislodged only by a current of water much stronger than can usually be found in a hot-water heating apparatus. The best remedy for air lock in a pipe is simply to straighten the pipe. Whether the bend which holds the air is long or short, or whether it occurs in the flow or return pipes, is of little consequence, because the effect is the same in all cases.

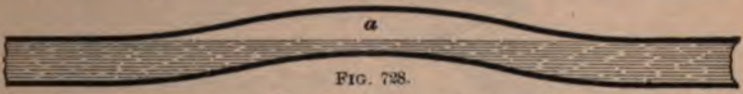

FIG. 728.

A bubble, or small air lock, in a local circuit will, in many cases, completely stop the circulation. Thus, when several radiators are so connected to the same supply and return mains that each one is on a local and practically independent circuit, the force which impels the water through them is so nearly alike in each, that the impediment caused by an air bubble lodged in one of the connections is usually sufficient to stop the flow through that circuit, and to divert all the hot water into the other circuits.

The manner of running and connecting pipes for hot-water service is practically the same as for steam heating. The expansion of the pipes by heat must be provided for by using spring pieces, expansion joints, etc., in the same manner.

1800. All **horizontal branches** from the flow main should be connected into the top of the main, or at least should be taken off by means of eccentric fittings, which will bring the top of the branch flush with, or a little above, the top of the main, so that all air bubbles may pass freely forwards and not accumulate in the main. All rising pipes should be connected into the top of a main, and never into the side or bottom.

In the case of indirect radiators which are set at a lower level than the main, the branch should always be taken from the under side of the main, and never from the top. If the branch rises from the top and then descends to the radiator, it forms a pocket in which air will inevitably collect and stop the circulation.

1801. In the **one-pipe system** the connections for a radiator are made about as shown in Fig. 729, *b* being the flow connection, *c* the return, and the main current moving through *a* in the direction of the arrow. The object here is chiefly to take the supply of hot water from the top of the main and return the cooler water into the bottom.

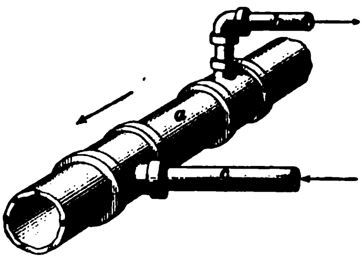

FIG. 729.

1802. Occasionally it is found necessary to make an upward **loop in a horizontal pipe,** in order to pass over a floor girder or similar obstruction, as in Fig. 730. The air will collect in the upper part of the loop; therefore, a

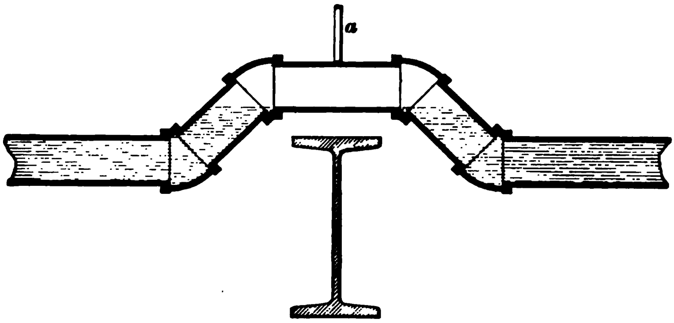

FIG. 730.

vent pipe *a* must be attached to it. As shown in the figure, the loop is constructed with four 45° bends and three nipples; consequently, the resistance to the flow of water will be considerable. It is advisable to make the loop by bending the pipe, and to avoid the use of fittings for this purpose, when possible.

Every pipe used in hot-water heating should be dressed smooth at the ends, and also be reamed, as shown in Fig. 720, for the general purpose of decreasing the resistance to the flow of water through the apparatus as much as possible.

CIRCULATION.

1803. The primary cause of the circulation of water by the force of gravity in a hot-water heating system is that the liquid becomes denser as it cools off, and, therefore, preponderates over the warmer and lighter water and pushes it to the top of the apparatus. It should be clearly understood that hot water will move only when there is a heavier and cooler body of water to displace it and force it upwards by means of its superior weight, or when some force other than the force of gravity is employed to move it.

The driving force which propels the water in any given circuit which operates by gravity alone is proportional to the *difference in the mean temperatures* of the ascending and descending parts of the circuit, and does not depend upon the actual quantity of water contained in these opposing parts of the system.

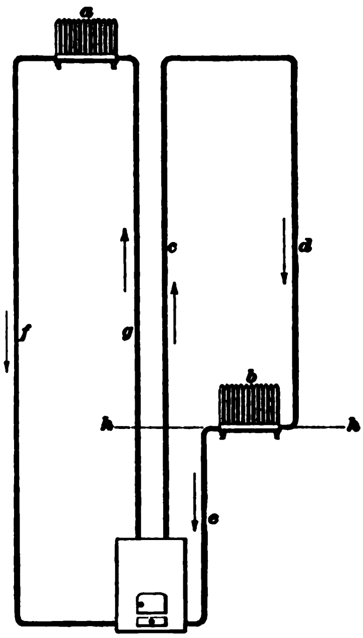

FIG. 731.

With a given difference in temperature, this driving force is also proportional to the vertical height of the circuit. Thus the motive force, or **head,** in a circuit 50 feet high would be twice as great as in one only 25 feet in height.

1804. The force of the circulation through radiators, etc., with a given fall of temperature, depends chiefly upon the height of the *return column*, and is, in many cases, practically independent of the height of the supply column. Thus, in Fig. 731, the circulation through the radiator *a* will be about three times as great as through *b*, notwithstanding the fact that the supply columns *c* and *g* are of equal height, because the return *f* is about three times as high as the return *e*. The temperature in the pipes *c* and *d* is supposed to be nearly the same; consequently, the column *d* simply balances an equal height of column *c*, and fails to supply any force for circulation. The force for circulation in this circuit, therefore, depends upon the preponderance of the water in *e* over that contained in the riser below the level of the radiator at the line *h*, *h*.

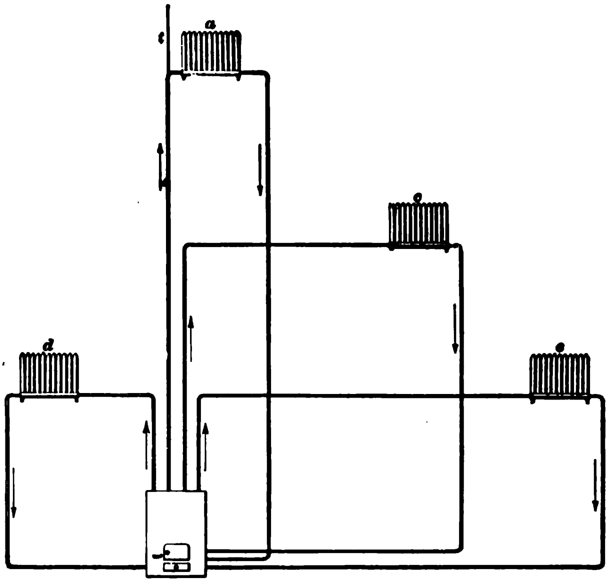

FIG. 732.

It will be seen that the only way in which the drop pipe *d* can be of service is to act as a *cooler*, and thus lower the temperature of the water which it contains. The same mechanical effect can be obtained, with less expense, by emitting an equal amount of heat from the radiator *b*.

1805. A **simple circuit** is one in which the water flows directly to a radiator through a single pipe without branches, and returns to the boiler through another direct and special pipe, as shown in Fig. 732. Although a large number of such circuits may be connected to a single boiler, each one is entirely independent of the others, and the force of circulation is governed by the actual height of each circuit and the difference of temperatures prevailing in it.

1806. In a **compound circuit** the supply current moves in a main pipe of comparatively large dimensions, commonly called the *flow main*, and the return currents proceed to the boiler through a similar pipe called the *return main*. These mains are connected by a number of small branches, each of which makes a direct circuit between the flow and return mains. The radiators are connected to these branches, usually one on a branch, sometimes more.

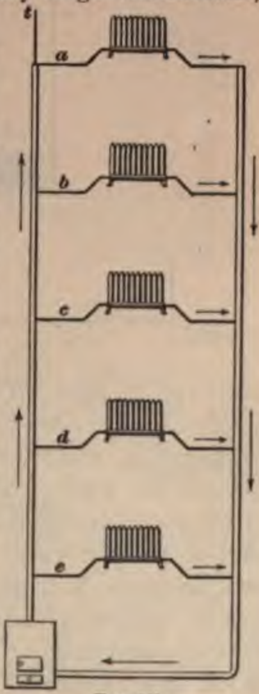

FIG. 733.

Compound circuits are arranged in many different ways, most of which are variations of the two systems shown in Figs. 733 and 734. In Fig. 733 the mains are vertical, and the branches are practically horizontal. In Fig. 734 the mains are horizontal and the radiators are attached to vertical branches or drop pipes.

In the former case, the effect of rapid cooling at any one radiator is to decrease the average temperature of the return main, and as all the radiators are connected to the same mains, the effect is divided and distributed over the entire system. In the latter case each radiator is independent, and the rapidity of the circulation through it will depend upon the amount of cooling which occurs at that point.

1807. In Fig. 734 the radiators *e* and *d* are supplied from the same **drop pipe,** and both are connected to the same return pipe. The circulation through the upper radiator will always be good, but as long as that one continues in operation, the lower one is likely to fail, being unable to get any hot water. This is due to the fact that the pressure of the cool water in the return between *e* and *d* overbalances that of the hot-water column in the flow connection to *d*, and prevents it from flowing through the radiator. The trouble can be remedied, however, by providing a separate return connection to the main *g*, thus making it independent of the upper radiator.

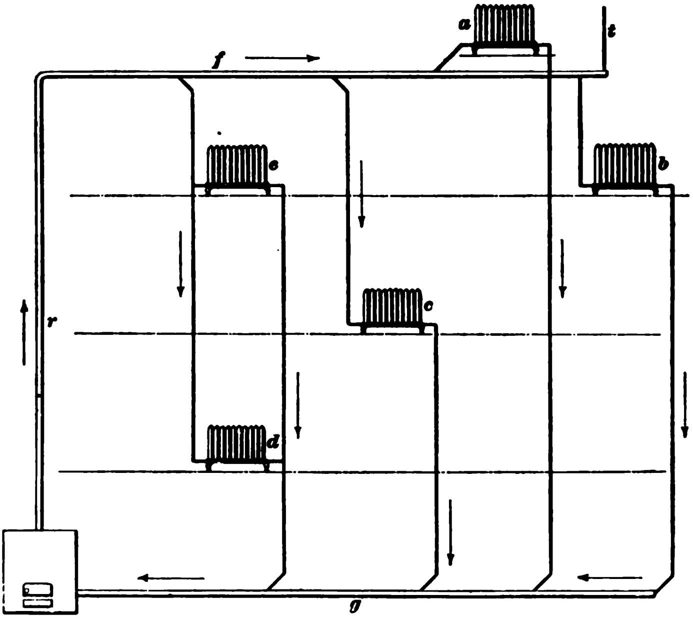

FIG. 734.

1808. Another method of operating a radiator on a drop branch, or with a downward moving supply, is shown in Fig. 735. The flow connection to the supply pipe is made at one level, and the return is connected into the same pipe at a lower level. The circulation through the radiator will depend mainly upon the vertical distance between the connecting points *d* and *e*. The flow connection may be made to the top of the radiator, as shown at *a*, or to the bottom as at *b*, as convenience may require. In the former arrangement each radiator will be supplied with hot water of practically the same temperature, but in the latter case the water in the drop pipe will be lowered in temperature by the cooler water which is returned from each radiator; consequently, the water supplied to the radiators at lower levels will be successively reduced in temperature. This will usually make it necessary to employ larger radiators on the lower floors, when this system is employed.

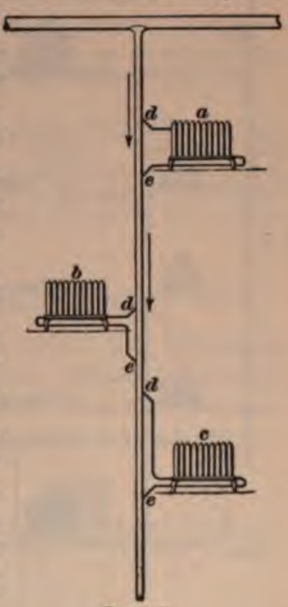

FIG. 735.

OPEN AND CLOSED CIRCUITS.

1809. In the plans shown in Figs. 733 and 734, the flow and return mains are connected only by the radiator branches, and there is no way of maintaining a flow of water through them when the radiators are shut off. This arrangement of mains is called an **open circuit.**

When the radiators are all shut off except one or two, the amount of circulation is likely to be too small to keep the water in the mains at a proper working temperature. In that case, when the other radiators are opened for use, considerable time must be spent in waiting for the whole system to heat up to the desired degree.

1810. This slowness may be obviated by keeping up at all times a good circulation through the mains regardless of the radiators, by connecting the flow and return mains by a pipe *k*, as shown in Fig. 736. This arrangement is called a **closed circuit.** The connection should be large enough to pass as much water as the whole number of radiators when in full operation. As long as a proper fire is maintained in the boiler, an active circulation will go on in the mains, and the water will always be at the maximum temperature, so that any or all of the radiators may be promptly supplied with hot water as soon as the valves are opened.

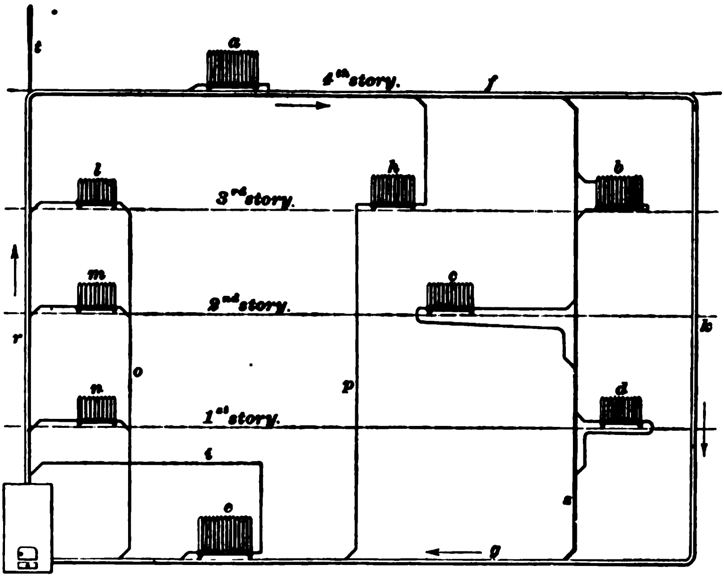

FIG. 736.

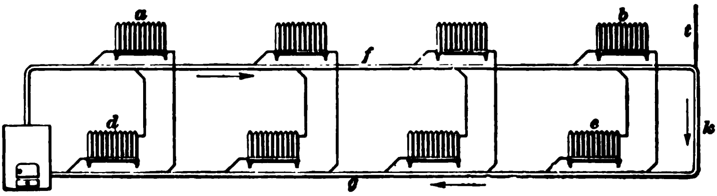

FIG. 737.

The closed circuit is desirable for all situations where the single circuit, Fig. 732, is not used, and is adapted to high buildings as well as low ones. It is superior to all others in long, low buildings of one or two stories, where the mains must extend a long distance horizontally, as in cases like Fig. 737.

NOTE.—There is quite a difference of opinion regarding the true meaning of the terms "open" and "closed" circuits. The terms and the meanings thereof, as here adopted, may seem contrary to common sense; but they coincide with the meanings of the same words when applied to electrical or other professions, and, therefore, will help to prevent confusion or misunderstanding.

ONE-PIPE, OR SINGLE-MAIN, SYSTEM.

1811. This system is commonly called the **one-pipe** system, but the term is wrongly applied. While it is practicable to operate a steam-heating system with a single main and with single connections to the radiators, it is wholly impracticable to do so with hot water. Hot-water radiators must have two connections. The nearest approach that can be made to a one-pipe system of hot-water distribution is to connect both the flow and return branches of the radiators to the same main, practically as shown in Fig. 738. The main is made of unusually large diameter, so that it acts as a reservoir, and the current through it is comparatively slow. The risers are tapped into the top of the main, and the

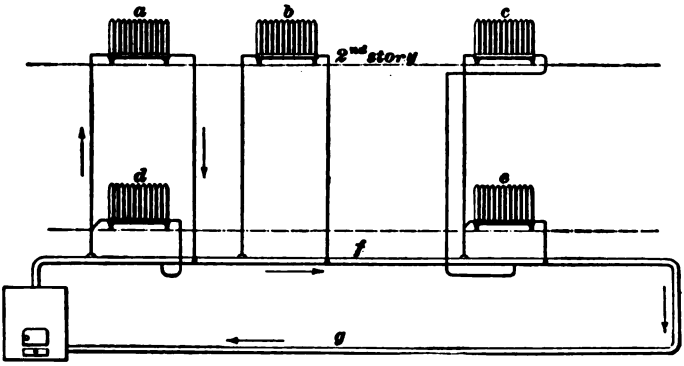

FIG. 738.

returns are connected into the side or bottom, so that they deliver the cooled water into the lower part of the main.

It is necessary that the temperature of the water be maintained at a proper degree throughout the whole length of the main, so that the water supplied to the radiators furthest away from the boiler will be reasonably hot; otherwise, the radiators supplied with the cooler water must be made too large, in order to compensate for the low temperature of the supply.

The main is usually connected back to the boiler by a return pipe *g*, thus making a closed circuit and ensuring a circulation through it at all times.

The main in a one-pipe system is usually carried around the basement walls exactly as is done in steam heating, and the return connection *g* is made near the boiler.

THE EQUALIZED SYSTEM.

1812. It frequently happens that radiators which are located close to the risers and have a free return circulation

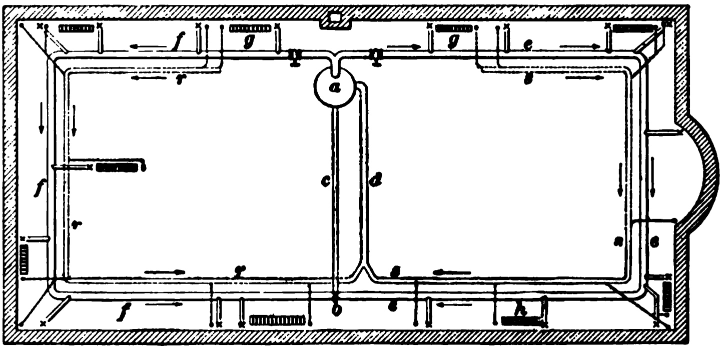

FIG. 739.

will take more than their proper share of hot water. This not only diminishes the supply for the more distant radiators, but the water thus passed through is discharged into the return main much hotter than it should be, and the motive force of the system is impaired thereby. To remedy this trouble, the system shown in Fig. 739 is sometimes employed.

The distinguishing feature of this system is that the water is compelled to travel exactly the same distance both in going to and returning from any radiator upon a given floor. Thus, a radiator situated close to the riser will have but little advantage over one situated a long distance away on the same level.

The flow main upon leaving the boiler *a* is shown divided into two sections *e* and *f*, which extend around the basement walls to the point *b*, where they unite. A return connection is made to the boiler by means of the pipe *c*, thus making a closed circuit. The return mains *r* and *s*, however, run in the opposite direction to that usually employed. They begin at the radiators *nearest* to the boiler, instead of the most remote, as in the common way. Thus, they begin at the radiators *g* and run along parallel with the flow mains until they finally unite into a single pipe *d*.

It will be seen that the water passing to the radiator *g* runs only a short distance in the flow main; but, since it is obliged to pass through the whole length of the return circuit, the aggregate distance traveled by the water in going to and from the radiator *h* is precisely the same. Thus the frictional resistance to the flow of water to all of the various radiators on the same floor is practically equalized if the pipes are properly proportioned.

PROPORTIONING A HOT-WATER SYSTEM.

1813. The principal object to be sought in designing a system of hot-water piping is to adjust and equalize the resistance in each circuit and branch, so that the hot water will flow with equal readiness to each radiator. This is accomplished by making the diameter of each pipe just sufficient to pass the desired amount of water under the **head** or driving force which is available in that particular part of the system. Artificial resistances are also introduced at some points by putting in extra elbows or bends, and valves are sometimes used for the same purpose.

An ordinary low-pressure system requires larger pipes than a high-pressure system, because the difference in temperature of the flow and return is less, and the driving force is consequently smaller.

VELOCITY OF FLOW.

1814. The driving force and volume being constant, the *velocity* of the flow through a circuit will be inversely proportional to the sectional areas of the pipes; that is, to the squares of the diameters.

Where the flow and return pipes in a single circuit are of the same diameter, the velocity will be the same in both. Water is practically incompressible; therefore, it must move simultaneously and equally in all parts of the circuit.

In a compound circuit the water is at liberty to move by several routes, and it always goes by the one which offers the least resistance. If several of the branch circuits are open at the same time, and the resistance is alike in each, then the water will flow equally through all of them, and the velocity will be reduced in inverse proportion to the number of pipes. But if the resistance varies in the several circuits, the main part of the flow will go through the pipes having a low resistance, and the circulation will be slower in the others.

In closed circuits, the flow of the water through the branch circuits is assisted by the momentum of the current which is kept moving through the mains, provided that the connections are made in a proper manner.

The actual velocity of the water in any given part of a compound circuit is difficult to compute, because of the number of variable influences which affect it. It is necessary to take into account the difference in temperature, the height of the returns, the resistance of the pipes, and the proportion of the total current which is passing through other circuits.

The theoretical velocity of the hot water in a single circuit is shown in the following table:

TABLE 72.

VELOCITY OF HOT-WATER CURRENTS IN FEET PER SECOND.

Height of Circuit in Feet.	Difference in Temperature.				
	10°	15°	20°	30°	40°
5	.75	.92	1.09	1.33	1.51
10	1.06	1.32	1.55	1.88	2.14
15	1.32	1.63	1.91	2.33	2.60
20	1.50	1.85	2.19	2.66	3.01
25	1.67	2.06	2.46	2.98	3.37
30	1.83	2.26	2.68	3.26	3.71
40	2.12	2.61	3.08	3.76	4.26
50	2.37	2.93	3.47	4.22	4.77
60	2.60	3.20	3.79	4.62	5.22
80	3.00	3.71	4.37	5.32	6.03
100	3.35	4.13	4.89	5.93	6.72

1815. The water must **fall in temperature** while passing through the radiator in order to emit heat. The rate of emission per hour being the same, the fall of temperature will be inversely proportional to the quantity of hot water passing through. Thus, if the temperature falls 10° with a supply of 100 cubic feet per hour it will fall 20° if the supply is reduced to 50 cubic feet per hour. It should be noted that the product of the temperature multiplied by the volume of the flow, or its velocity, will be a constant figure.

Therefore, in order to compute the quantity of water to be supplied or the size of the pipe to supply it efficiently, it is necessary to determine in advance what the fall of temperature shall be at each radiator.

The fall of temperature usually allowed in good practice is 20°, and 35° is regarded as the limit in any case.

1816. Height of Circuit.—The horizontal pipes on the upper floors of a building, and also the risers leading thereto, may be made smaller in diameter than those upon the lower floors, because the driving force which impels the water increases with the height of the circuits, as previously explained.

The proper size of a pipe having been determined for a given service on the first floor, the diameter for equal service on higher floors—the temperatures remaining the same—may be found by multiplying by the following factors:

Story	2d	3d	4th	5th
Factors	.87	.80	.76	.73

No factors are given for heights above the fifth floor, or about 50 feet, because the decrease for the succeeding stories is so small as to be of little practical account.

Conversely, *the area of heating surface that may be properly supplied by a pipe of given diameter will increase as the circuit is made higher.* If the area which is known to be right for a given size of pipe on the first floor be taken as 1, the areas on the upper floors will increase in the following order:

Story	2d	3d	4th	5th
Proper area heating surface	1.40	1.70	1.98	2.20

RESISTANCE OF CIRCUITS.

1817. The frictional resistance to the flow of water through pipes varies directly as the length of the pipe, inversely as the area of the pipe, and directly as the square of the velocity. Therefore, all three of these things must be fully considered in determining the proper diameter to be given to the various pipes composing the apparatus.

The resistance caused by elbows, tees, and other fittings, is considerable. The resistance in a bend made with a common elbow, the ends of the pipes being left square, is about equal to the frictional resistance of a piece of straight pipe having a length equal to 100 times its diameter. If the ends of the pipes are beveled to an edge, as shown in Fig. 720, the resistance may be reduced to that of a length of 70 diameters, or even to 60 in small sizes. With a long bend having a radius of 5 diameters, the resistance falls to 10 diameters, or less.

A plain **T** offers about the same resistance as an elbow, and a return bend from 1½ to 2 times as much. The gain made by beveling the ends of the pipe is much less in large diameters than in small ones.

In estimating, for purposes of computation, the length of any given circuit, an addition should be made to the measured or actual length sufficient to equal in resistance the total resistance offered by the fittings. For example, in a circuit having an actual length of 300 feet, there are say 8 elbows and 12 tees. Allowing 70 diameters for each elbow and **T**, the length to be added to the actual length of circuit to represent the resistance of the fittings would be $(8 + 12) \times 70 =$ 1,400 times the diameter of the pipe. In the case of a 4-inch pipe this would equal 467 feet, making the estimated length $300 + 467 = 767$ feet.

The *actual* length of a circuit is always understood to be the actual distance traveled by the water in going from and returning to the boiler.

When the water flows through pipe coils, the actual distance traveled must be ascertained and included in the estimate of length of the circuit, and full allowance must be made for each return bend. It is found by experience that the ordinary flow and return connections from a radiator to the risers, or mains, which have an aggregate length of about 10 feet, and include six ordinary elbows or their equivalents, will present about the same resistance to the flow of water as a plain, straight pipe 100 feet long. Therefore, in computing the friction in a circuit, about 100 feet should be added to the actual length for each ordinary radiator connection.

For general purposes it is assumed that the water will cool 20° in passing through the radiators, and will thus emit 20 heat units per pound, or 166.7 units per gallon.

SIZE OF PIPES.

1818. There are two modes of determining the proper sizes of hot-water piping, as follows: In the *first* method, the amount of heat to be emitted from the radiators per minute is ascertained and divided by 166.7, which gives the number of gallons of water required per minute with a fall of temperature of 20°. If any other range of temperature is adopted, this divisor must be changed to suit. Having found the flow required, the diameter of the pipes is then computed by the ordinary laws of hydraulics, as fully explained in previous articles.

The *second* method is by the use of tables, which are prepared from data furnished by experience in actual practice, rather than from the data derived from theoretical investigation. It is assumed that each radiator will be always working at its maximum capacity, and that the fall in temperature of the water will be 20°. Therefore, Table 73 is based upon the area of the radiator surfaces instead of upon the heat units emitted.

The first method is by far the more accurate, but it requires considerable computation, and in practice it is unnecessary that the pipes should be so accurately sized. It is always necessary that the pipes should be large enough, but no harm is done by having them larger than required, except that the cooling surface exposed by the pipes is somewhat increased. This method is most valuable where very long circuits are to be used, and also in cases where the heating is done by the single-circuit system.

The second method is convenient and is better adapted to the various compound-circuit systems. The error, if any, is always in favor of a freer circulation of the water, so that the fall of temperature will be somewhat less than 20°, and the radiators will then emit a little more heat than rated. If a pipe is larger than needed, the flow can be checked by putting a suitable bushing at the radiator inlet; but if it is too small there is no remedy. The fall of temperature will then exceed 20°, and the efficiency of the radiator will be reduced.

1819. Mains.—Table 73 shows the amount of heating surface that can be properly supplied with hot water by mains of a given size and uniform diameter throughout their whole length, the radiators being located upon the first floor. The amount of radiator surface that can be maintained on higher floors may be found by multiplying the amount shown in the table by the factors given in Art. **1816.**

TABLE 73.

SIZE OF HOT-WATER MAINS.

1820. Diameter of mains required to properly supply a given area of direct heating surface. Fall of temperature, 20°. Height of circuit, between 10 and 15 feet.

Diameter of Mains.	Total Estimated Length of Circuit in Feet.									
	100	200	300	400	500	600	700	800	900	1,000
1	20									
1¼	35	20								
1½	56	40	25							
2	116	85	70	50						
2½	220	150	120	100	90					
3	345	240	200	170	150	140	125	110	100	90
3½	500	340	280	245	225	205	190	175	162	150
4	700	485	390	340	310	280	260	240	230	220
4½	925	640	535	460	410	375	345	325	300	295
5	1,200	830	700	600	540	490	450	420	400	380
6	1,900	1,325	1,100	950	850	775	700	650	620	600
7		2,000	1,600	1,400	1,250	1,140	1,050	975	925	875
8				1,970	1,720	1,550	1.440	1,350	1,300	1,250
9							1,900	1,800	1,700	1,620

1821. Risers.—Table 74 shows the area of radiator surface, in square feet, that can be properly supplied at various elevations by risers of a given diameter. The radiators are supposed to be connected by ordinary short connections having a total length of about 10 feet. Each story corresponds to a height of about 10 feet.

TABLE 74.

SIZE OF HOT-WATER RISERS.

1822. Diameter of risers required to properly supply a given area of direct heating surface. Fall of temperature, 20°.

Diameter of Riser. Inches.	Story Where Heater is Located.					
	1	2	3	4	5	6
¾	12	17	21	24		
1	22	32	40	48		
1¼	38	56	70	80	88	
1½	66	92	112	132	145	
2	140	196	238	280	310	
2½	240	328	400	470	515	
3	350	490	595	700	770	850
3½	510	705	860	1010	1110	1215
4	700	980	1190	1280	1540	1660

There is a practical limit to the vertical length of risers that can be used to advantage, especially in the smaller sizes of pipe. If a small riser is extended to a great height, the friction of flow becomes excessive, and the quantity of water delivered will be much smaller than it would be with less height. The limits for the various diameters are about as follows:

Diameter in inches..........	¾	1	1¼	1½	2.
Height in feet..............	20	30	45	60	80.

For example, a riser is diminished in diameter at successive floors until only a ¾-inch pipe is needed for supplying the highest radiator; if the height of the extension is more than 20 feet, then the next larger size of pipe, that is, 1-inch, should be used.

The practical limits stated above are due to the increased resistance resulting from increased velocity, and reduction in size of the pipe.

1823. Size of Radiator Connections.—In the following table the area of radiator surface is given, corresponding to connections of the given diameters, for service on the first floor, that is, at an elevation between 10 and 15 feet above the level of the return connection to the boiler. It is assumed that the aggregate length of the flow and return connections is about 10 feet, and also that they include six elbows or their equivalents, the resistance offered by such connections to the flow of water being the same as that of 100 feet of plain, straight pipe:

TABLE 75.

DIAMETER OF RADIATOR CONNECTIONS.

Fall of Temperature, 20°.

Size of Pipe in Inches.	¾	1	1¼	1½	2	2½
Area of Direct Heating Surface in Square Feet..	16	24	40	60	120	240

If the area of heating surface exceeds the amount given, the fall of temperature will exceed 20°, and if it be less, the fall will be less correspondingly. If the connections are long or crooked, less heating surface can be operated, or a larger drop in temperature will occur.

1824. The **pipes for indirect heating** apparatus must be made larger than for direct heating, because the motive power of the circulation is usually smaller, and also because the indirect radiators emit more heat per square foot per hour, and, therefore, require more water per square foot of surface.

In order to find the proper sizes of pipes for indirect heating apparatus by means of the given tables, it is necessary to convert the area of indirect heating surface into an equivalent area of direct heating surface. This should be done by adding 50 per cent. to the actual area of the indirect radiators. Thus, 100 feet of indirect surface should be reckoned as 150 feet of direct heating surface, for purposes of computation.

The manner of determining the proper sizes of the various parts of a hot-water pipe system by means of the foregoing tables will be explained by the aid of Fig. 740. This

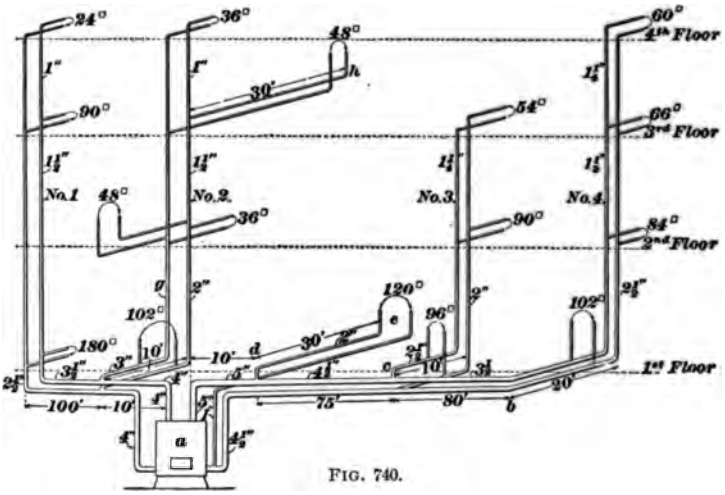

FIG. 740.

is a diagram showing the area of heating surface required at each radiator, the height of the various risers, and the length of the horizontal branches and mains. The vertical lines represent risers, the horizontal lines represent mains, and the oblique lines indicate horizontal branches extending at right angles from the pipes to which they are attached. The horizontal dotted lines indicate the several floor levels. The figures having the symbol □ attached to them — thus, 60 □ — indicate the area in square feet of the radiator at that branch. The risers are numbered No. 1, No. 2, etc., for convenience of reference. The length of each horizontal branch is noted in feet, and the lengths of the several parts of the mains are also noted.

Having a suitable working drawing, the work of computing the diameters of pipes should begin at the point most remote from the boiler, which, in this case, is the radiator on the fourth floor on riser No. 4.

The riser must supply water sufficient for 60 square feet of heating surface at that point. Referring to Table 74, it appears that on the 4th floor a 1-inch pipe is best adapted to 48 square feet, while a 1¼-inch pipe will serve 80 square feet. If the 1-inch pipe is used, the fall of temperature at the radiator will be more than 20°; therefore, it is advisable to use the 1¼-inch pipe.

The pipe leading from the 2d to the 3d floors must supply the 60-foot radiator on the 4th floor and also the 66-foot radiator on the 3d floor—a total of 126 square feet. The table shows that 126 feet on the 3d floor will be nearly supplied by 1½-inch pipe, while the next size, 2-inch, is much too large. If there were no radiator on the second floor, it would be advisable to use the 2-inch pipe from the 66-foot radiator down to the mains.

The riser from the main to the 2d floor must supply three radiators, aggregating 210 square feet. The table shows that 2-inch pipe is a little too small, while 2½-inch is larger than necessary. But it should be noted that there are elbows at the foot of these pipes; therefore, it is as well to use the 2½-inch diameter.

The sizes of the other risers should be determined in a similar manner. The horizontal lines may then be considered. That part of the mains extending from No. 4 riser to the connections to No. 3 must supply a first-story radiator in addition to No. 4 riser, aggregating 312 square feet. The length of the flow pipe is 100 feet, which, added to the same length of return pipe, makes a circuit of 200 feet. Referring to Table 73, it appears that 312 square feet of surface, on a 200-foot circuit, requires a 3½-inch pipe. This size is a little larger than that actually required, and will compensate for the elbows at *b*.

At the point *c* another circuit No. 3 is attached, which supplies 240 square feet of heating surface, making the total surface to be supplied at that point $240 + 312 = 552$ square feet. The distance between the points *c* and *d* is 75 feet, making the circuit 150 feet long. The table shows that 552 square feet of surface, on a 200-foot circuit, requires a 4½-inch pipe. The return may be continued to the boiler with that size, but the flow main should be enlarged at *d* to provide for the radiator at *e*.

The length of the connections to this radiator is so much greater than is ordinarily the case that the circuit should be considered as a 100-foot circuit. The table shows that 120 square feet of surface requires 2-inch pipes.

It will be noted that this radiator is also provided with an independent return connection, as shown at *f*. This construction ensures a good circulation, more positive and rapid than if the return were connected into the return main at *d*. The difference is owing to the length of the horizontal branches. If the radiator were located close to the mains, there would be no great advantage in providing it with an independent return.

The circulation in circuit No. 2 would probably be improved by providing the return pipe *g* with an independent connection to the boiler, instead of connecting it to the return main, as shown in the drawing.

The radiator *h* on circuit No. 2 has long connections. It was explained in Art. **1816** that a given size of pipe will supply 1.7 times as much heating surface on the third floor as on the first; therefore, this radiator corresponds to one on the first floor having $48 \div 1.7 = 28$ square feet of surface. Table 73 shows that a radiator of that size on a 100-foot circuit requires 1¼-inch pipes.

PROPORTIONING CLOSED-CIRCUIT SYSTEMS.

1825. In single-circuit systems, like Fig. 732, the size of the risers may be computed by Table 74, and the size of the horizontal pipes by Table 73.

In a compound system like Fig. 736, the conditions are very different from those prevailing in an ordinary open-circuit system like Fig. 739. The water in the main circuit *r f k g* moves constantly, whether the radiators are in operation or not. The quantity passing up *r* must always be sufficient to supply all the radiators in the system, and the water will return to the main *g* either through the several drop pipes *o*, *p*, *s* or through the main drop *k*, according as the radiators are or are not in use.

The motive force in the main circuit depends upon the height of the system, which, in this case, is four stories. Therefore, the size of the riser should be calculated to pass the total quantity required, under the head of four stories. The case is the same as if all the radiators were located upon the fourth, or top, floor.

The size of the horizontal mains *f* and *g* may be found from Table 73. In order to use the table, the total actual area of radiator surface must be reduced to its equivalent at the first floor. This is done by dividing it by the figure given for the fourth floor, in Art. **1816**, as before explained.

These pipes may be larger than the riser, but should never be smaller. The drop pipe *k* should be made of the same size as the riser in all ordinary cases, to ensure a proper circulation and maintain a high temperature in the main circuit.

The drop pipe *o* should be increased in size as it descends, in the same manner as the returns in Fig. 739. The drop pipe *s* has three radiators attached to it which use the same water successively; consequently, the total fall in temperature will probably exceed 20°. But the average temperature in the pipe, when all three radiators are in use, should be about 20° below that in the main *f*. Therefore, it should be considered as an ordinary return pipe descending from the fourth story.

In Fig. 736 the pipe *k* may be entirely dispensed with, if *s* is made large enough and has no valves in its length. If ordinary fittings are used to connect *b*, *c*, and *d* to *s*, the circulation through each of these radiators will be sluggish, because the main current will by-pass them, and any circulation through them will depend upon the drop given to their respective return branches.

SYSTEMS OF HEATING.

1826. In hot-water heating, the choice of a system for any particular building or for special service depends upon the local circumstances in each case.

1827. In the **high-pressure system** the temperature of the water for heating purposes may be anything from 212° to 400°, or even more. *Where there is no objection to high temperatures and the accompanying risks*, it may be used in preference to the low-pressure system. It requires stronger boilers and radiators, the pressure at 350° being about 121 pounds per square inch by the gauge, but the apparatus is much smaller than that used for low-pressure heating. The range of temperature at the radiators is large, amounting sometimes to 150° or more; consequently, the pipes may be made quite small. Usually, however, the range is about 50° or 60°, which means that the radiators also may be small. This gives a motive force about three times as great as in low-pressure apparatus.

1828. The **low-pressure system** operates with a maximum temperature of 210° or 212°, and the range of temperature is usually 20°. The area of heating surfaces must, therefore, be quite large. The motive force is so small that in large jobs the size of distributing pipes and mains becomes very inconvenient. These large pipes also add greatly to the cost of the apparatus.

For ordinary dwellings the low-pressure system has substantial advantages. It is not liable to damage by explosion or by neglect. It can be operated by any person capable of maintaining a proper fire in the boiler, and if properly erected can not get out of order.

1829. The system shown in Fig. 740, sometimes called the **parallel system,** is best suited for ordinary dwellings.

If the building is large and covers a considerable area of ground, so that a large number of risers is necessary, some advantage can be gained in force of circulation by continuing the flow main around to a point opposite the boiler and making a return connection, thus forming a closed circuit.

The single-circuit system has the advantage of positive and direct circulation in each circuit, so that the heat required at each radiator can be accurately provided for. It therefore requires less skill in designing than systems like Figs. 740 or 736. The system is objectionable, except for small jobs, because the number of pipes running to and from the boiler becomes so great that they are very inconvenient, and also quite expensive.

In stores and office buildings where there are a large number of radiators on a single-main circuit, each being controlled by a different person, the advantage of having the circuit closed is of great importance.

The one-pipe system has no apparent advantages, except that in some cases it is cheaper to install. The circulation in each radiator depends solely upon the actual height of its individual return column, and the system as a whole is very sluggish.

STARTING AND TESTING.

1830. In making a test of hot-water heating apparatus, it is necessary that the whole apparatus be tested together. It can not be done in sections, as in steam heating, because the main question to be settled is whether the water will circulate properly at every radiator when the entire system is in use. If the system is divided into several sections, which are designed to be operated independently when others are shut down, separate tests should afterwards be made of each section when working alone.

It may be found that, while the different sections work properly alone, they will interfere somewhat when all are operated together; some circuits will take more than their proper share of the water and will thus rob the other circuits. This trouble can usually be remedied by bushing or reducing the return connection slightly, where it joins the main, or where it enters the boiler, if the return be an independent one.

Before starting a test, every radiator should be supplied with an air vent, and every place in the piping that might accumulate air should also be thoroughly vented. Care should be taken to see that every radiator valve, and also every valve in the piping, if there are any, is wide open. Having attended to these preliminaries, the apparatus may then be filled with water. The water should be introduced at the bottom, and rise gradually upwards, driving the air before it. Every air vent, etc., should then be opened until water flows out.

Fresh water always contains a considerable percentage of air or gas in solution, and as soon as the water becomes heated the gases will be liberated in bubbles. If the apparatus is properly vented, there will be no difficulty in getting rid of this air; it is very essential, however, that this water be discharged from the pipes or there will be trouble

After the apparatus has been run with a full fire long enough to become thoroughly heated up, the circulation may be tested. The only convenient method of doing this is to apply thermometers at every point where it is desired to note the fall of temperature. An excessive fall of temperature denotes that the flow is insufficient, and a small fall shows that more water is being received than required. The mode of applying thermometers is fully explained in Arts. **1411** to **1414.**

If the heating system is of the closed variety, the safety valve should be adjusted so as to open at the right pressure.

HEATING GREENHOUSES.

1831. Greenhouses may be heated satisfactorily with either steam or hot water, but the latter is generally preferred, because of the simplicity of the apparatus, and its ability, when properly arranged, to store up large quantities of heat. The apparatus is made to contain an amount of water which is very large in proportion to the cooling surfaces of the greenhouse, thus constituting a reservoir of heat. If the fires burn low or go out, the stored heat is given out gradually and serves to keep the temperature from falling too rapidly, thus protecting the plants from damage until the fires are attended to.

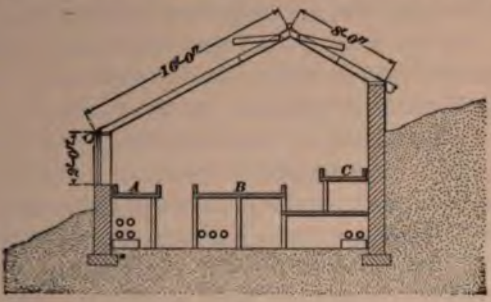

FIG. 741.

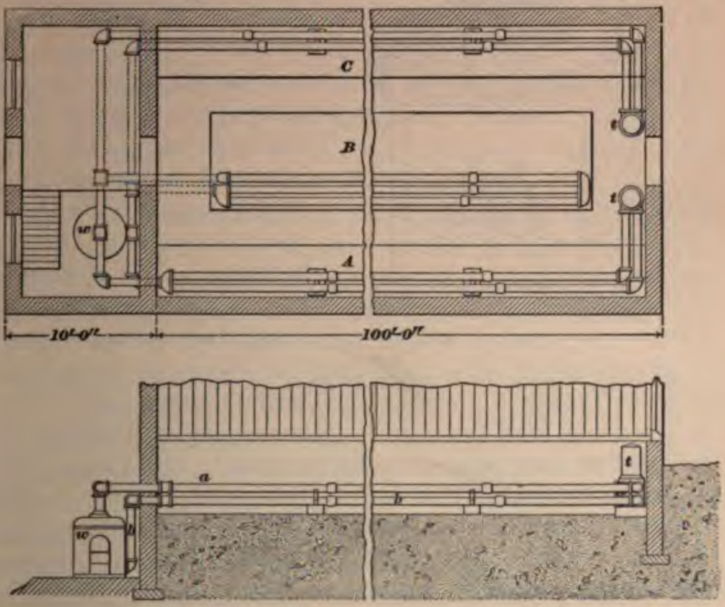

FIG. 742.

1832. In order to understand the requirements of a greenhouse, it is necessary to know something of the construction and general arrangement of such buildings. Figs. 741 and 742 show a greenhouse which is supposed to be located on the side of a hill. It is constructed with two or three large parallel benches, or platforms, *A*, *B*, *C* which run the whole length of the building, for the purpose of holding plants which grow in pots; or they may contain a bed of earth or sand in which seeds and cuttings are propagated. The outside, or wall, benches are arranged as shown in Fig. 743. A space about 2 or 3 inches wide is made at *g*, between the bench and the wall, so that the warm air rising from the heating pipes will pass upwards in a sheet, as it were, in front of the windows *H* and thus neutralize the downward current of cold air which would otherwise exist at that point. The front edge of the bench is extended downwards, as at *f*, to ensure the movement of the air up the passageway *g*, as described. The heating pipes *a* *b* are supported by iron plates *c*, *c*, which are cast especially for the purpose. The propagating benches are enclosed on both sides, partially or entirely, down to the floor, so as to retain a body of hot air in contact with the under side of the bench, or **bottom heat,** as it is commonly called. For some classes of work little or no bottom heat is desired, and only **top heat** is used, that is, the heat derived from the warm air in the upper part of the room. The apparatus must be arranged, therefore, so that the heat may be applied beneath the benches, or to the air in the body of the house, sometimes both, according to the use made of the building.

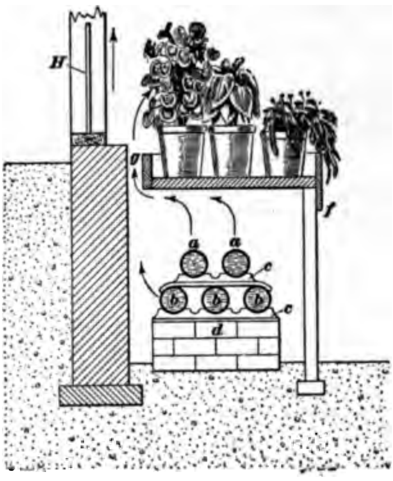

FIG. 743.

1833. It is necessary to control the temperature at each bench, in order to grow plants to the best advantage; therefore, each set of pipes must be provided with suitable valves, such as that shown in Fig. 726.

When steam is used, it is necessary to place shut-off valves on every line of pipe which extends beneath the benches, and the only practicable mode of regulation is to shut off the steam from a greater or less number of the pipes. The vacuum system of steam heating is peculiarly well adapted to greenhouse service, but is usually too expensive for ordinary greenhouses.

HEATING SURFACE REQUIRED.

1834. The loss of heat from a greenhouse occurs principally by conduction through the glass, and to a great extent by leakage around the edges of the sashes and at the laps of the glass. The loss through the side and end walls may be computed as one-fourth of that through an equal area of glass. When the difference between the interior temperature and that of the outside air is 70°, each foot of glass will emit 55 to 60 heat units per hour.

The pipes commonly used for hot-water service in greenhouses are slightly less than 4 inches in diameter, 1 lineal foot of pipe being equal to 1 square foot of heating surface. If the average temperature of the pipe is 100° above that of the air in the room, each square foot of pipe surface, or 1 lineal foot of the pipe, will emit about 165 to 180 heat units per hour when the system is operating under moderate conditions. Thus it appears that for hot-water apparatus, the area of heating surface should be about one-third of the estimated area of glass and equivalent surfaces.

1835. The following ratios have been found in practice to give good results, and may be used in designing heating systems for greenhouses. The external temperature is supposed to be 0° F., the exposure of the greenhouse moderate, and the construction good.

TABLE 76.

RATIO OF GLASS TO HEATING SURFACE.

	Steam.	Hot Water.
For 45° inside temperature, divide glass surface by	8.0	5.00
For 50° inside temperature, divide glass surface by	7.0	4.50
For 55° inside temperature, divide glass surface by	6.5	4.00
For 60° inside temperature, divide glass surface by	6.0	3.50
For 65° inside temperature, divide glass surface by	5.0	3.25
For 70° inside temperature, divide glass surface by	4.5	3.00

With steam at 5 pounds pressure, and a temperature of 227°, the pipes, which are usually 1¼-inch bore, will emit 320 to 360 heat units per hour per square foot of surface; consequently, the ratio of heating surface to glass surface may be about as 1 to 6.

ARRANGEMENT OF PIPES.

1836. As previously stated, cast-iron pipes of large diameter are generally used, but wrought-iron pipe of the same size may also be used to equally good advantage. The pipes are usually laid in long parallel lines under the benches, as shown in Figs. 742 and 743, with one or two flow pipes *a* resting on top of two or three return pipes *b*. They are supported at intervals by brick piers *d*, at a sufficient height above the floor to secure a good supply of air to the inside of the group of pipes. They are all laid upon an upward grade from the boiler to the further end of the line.

1837. The **head** available in greenhouse apparatus is seldom more than 6 feet, and is usually much less. As the buildings are frequently from 300 to 400 feet long, it is evident that the grading of the pipes must be carefully done. In order to secure as much head as possible, the boiler should be set in a pit or cellar.

1838. The **expansion tank** is usually placed at the end of the line of pipe most remote from the boiler. Each line or group of pipes may be provided with an expansion tank, or one large tank may be used for the whole system. The expansion tank is usually arranged as shown in Fig. 744. Both the flow and return pipes are connected to it as shown; thus, it serves as a return connection and also as a vent for air. The top is closed by a loosely fitting cover.

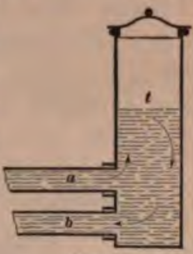

FIG. 744.

When the water is cold it should stand 3 or 4 inches above the opening into the flow pipe *a*, and the space above that level should be equal to at least $\frac{1}{20}$ of the volume of water contained in the whole apparatus. Of course, if several tanks are used, this space for expansion may be divided between them. In the plan view, Fig. 742, the pipes shown under the side tables are provided with separate tanks *t*, while the middle line has none. As it may be inconvenient to place a tank at the end of the middle table, it is therefore omitted in the drawing. These pipes are relieved of air by means of a $\frac{1}{4}$-inch or $\frac{1}{2}$-inch pipe, which is tapped into the highest point, and is extended upwards above the level of the top of the expansion tanks. The boiler *w* is set in a pit, as shown in the side elevation.

1839. Making Joints.—The cast-iron pipes usually employed for greenhouse heating are connected by the ordinary spigot joints, but are not calked with lead because this is not durable in hot-water work. The expansion and contraction of the pipes soon works the lead rings out of the joints, so **rust joints** are used instead. The cement is made by mixing 100 parts, by weight, of iron filings or borings, pounded fine, with from 1 to 2 parts of sal-ammoniac, enough water being added to make the mixture into a thick mortar.

The bottom of the socket is closed by calking in a strand of oakum in the usual manner, and then the remaining space is filled with the cement and lightly calked. The sal-ammoniac attacks the iron and rapidly converts it into rust, which hardens into a dense, tough mass, and clings to the iron pipe with great tenacity.

1840. The hot-water system can also be applied by using small **wrought-iron pipes,** as in ordinary house heating. In this case the flow main *a* should be carried along overhead near the roof to the farther end of the greenhouse, and only the return pipes *b* should be placed under the benches. The main should be taken directly up to the expansion tank and then be graded from the tank to the further end of the greenhouse. The returns should be inclined downwards towards the boiler. (See Fig. 745.)

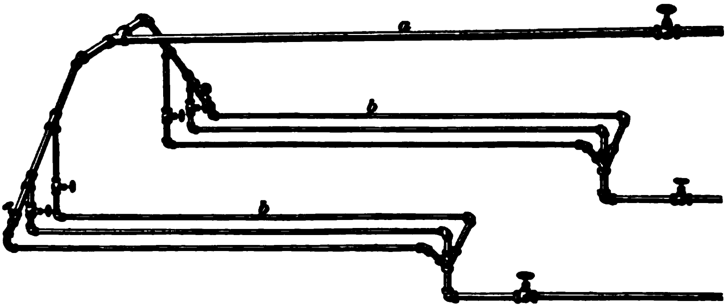

FIG. 745.

For steam heating, the pipes should be arranged in the same way, so that the condensed water will travel in the same direction as the steam.

The pipes employed under the benches are usually 1¼ inches in diameter for steam, but for hot water the size must be governed by the length of the circuit and the head available; in any case, a diameter of 1½ inches should be the smallest size. In using steam, the boiler may be set at any convenient level, and no pit is needed.

FURNACE HEATING.

HOT-AIR FURNACES.

DESCRIPTION OF FURNACES.

1841. A hot-air furnace may be described as a device for heating a continuous current of air by means of a fire contained within the apparatus, and without mingling the fresh air with the products of combustion.

It combines the functions of a heat-generator with those of a radiator, and operates without the aid of any intermediate heat-carrying agent. The transmission of heat is direct, through a single plate or sheet of metal, from the fire or hot gas on one side to the fresh air on the other.

It is evident, therefore, that, in order to operate effectively, the construction of a hot-air furnace must conform both to the laws which govern the absorption of heat from hot gases, and also to those which control the emission of heat from hot surfaces. Many of the varieties of hot-air furnaces now upon the market are built with little regard to these laws, and consequently possess a very low degree of efficiency.

1842. It has already been shown that air can not be heated by *radiant* heat, and that the only practicable method of heating it is to bring it into *actual contact* with hot surfaces. Many forms of furnace seem to have been designed with the idea that the air can be heated sufficiently by bringing it within the range of the radiant heat which is emitted from the fire-pot and other hot parts, and that the actual *area* of the heating surfaces presented to the air is a matter of minor importance. Nothing could be further from the truth. The radiated heat is useless unless it is

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intercepted and absorbed by some surface which will impart this heat to the air by contact and conduction. Hence, the efficiency of a furnace depends, in a great measure, upon the area of the hot surfaces over which the air is passed.

1843. Extent of Heating Surfaces.—The rate of transmission of heat by conduction from hot gases to a metal plate, or from a hot plate to the air passing over it, is strictly proportioned to the difference in temperature between them, as already explained in the second section on Heating and Ventilation. The actual rate of transmission to air is, however, much slower than the transmission from steam to metal or from metal to water; consequently, the proportion of heating surface to the amount of fuel burned should be much greater in a hot-air furnace than in a steam boiler. The proportion of heating surface to grate area in steam-heating boilers ranges between 20 and 45 to 1, averaging about 35 to 1. The ratio in the hot-air furnaces now in general use is nearly the same, but ought to be much larger. In order to obtain the best results, the ratio should average about 50 to 1.

The heating surfaces in a hot-air furnace should be sufficiently extensive to cool the hot gases of combustion, before they pass into the chimney, to a point not more than 100° above the temperature of the heated air which is discharged into the warm-air pipes. Any greater excess of temperature is unnecessary and wasteful.

1844. Arrangement of Heating Surfaces.—In general features, the construction of a hot-air furnace should approximate to that of a tubular or water-tube boiler. The hot gases upon the inside, and also the fresh air on the outside, should be divided into thin sheets or small streams, and should be conducted through tubular channels or narrow passageways having large areas of hot surface in proportion to the volume of the current. The hot gases should impinge upon the heat-absorbing surfaces as nearly as possible at right angles, and the movement of the gases should be in the opposite direction to that of the air.

On account of the slowness of the transmission of heat to or from air and gases, it is necessary that the channels through which they pass should have considerable length, so that while the currents move with proper velocity, plenty of time will be afforded for giving up the heat. A momentary exposure of the air to a red-hot surface is far less effective than a prolonged exposure to surfaces having only a moderate temperature. *Time* is an important element in heating air

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TYPES OF FURNACES.

1845. Fig. 746 shows the construction of a common and cheap variety of hot-air furnace. The fire is contained in the fire-pot *a*, and the products of combustion fill the combustion chamber *b* and pass off through the smoke-pipe *c*. The fresh air enters through holes in the base-ring *d*, and passes upwards between the casing *e* and the fire-pot and combustion chamber, and escapes to the leading pipes through holes in the bonnet *f*. It will be noted: *First*, that the air is heated only while passing from the top of the ash pit *g* to the top of the combustion chamber *b*. *Second*, although the top, or "dome," *h* is quite hot, it has but little opportunity to impart heat to the air, because there is little or no circulation over it. If the air were taken off at the center of the bonnet instead of around the sides, the dome would do much more effective work. *Third*, the heat which is radiated from the fire-pot and combustion chamber is in part absorbed by the jacket, which thus becomes warm. This heat is imparted to the air passing up

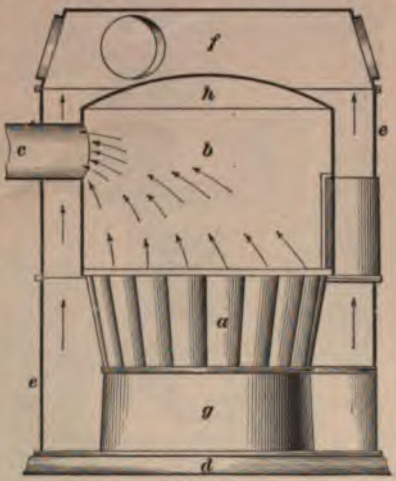

FIG. 746.

inside and also to the air upon the outside, the latter portion being practically wasted. *Fourth*, the hot gases pass into the chimney in such a direct manner that the greater part of the stream does not come in contact with the walls of the combustion chamber. Thus, the gases escape without giving off the proper amount of heat to the air which is to be warmed.

1846. Fig. 747 shows a mode of construction by which the passage of the hot gases to the chimney is prolonged considerably, and at the same time the area of the heating surface is greatly increased. The combustion chamber *b* is surrounded by a circular flue or belt *k*, which opens into it at a point in front of the fire door. The hot gases enter the belt as shown by the arrows, and pass around to the rear, where they discharge into the smoke-pipe. The air to be warmed is divided into two main currents, one of which passes upwards between the furnace casing and the belt *k*, in the usual manner, and the other goes up through the air-space *m*. Both currents are spread out into thin sheets, thus securing very favorable conditions for rapid and effective heating. In this figure, as in Fig. 746, *g* is the ash pit, *a* is the fire-pot, and *h* is the dome of the combustion chamber.

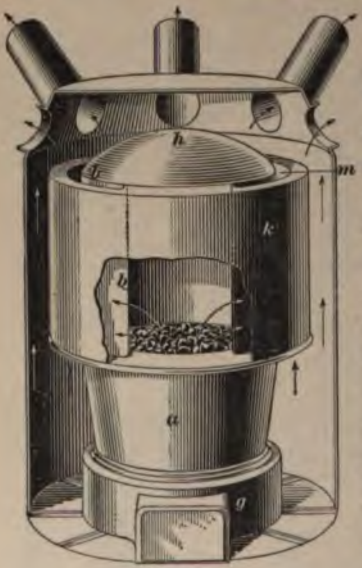

FIG. 747.

1847. In Fig. 748, the area of the heating surface is increased by employing a large circular top flue *n*, which is connected to the combustion chamber by a large number of short vertical flues *p*. The *dome*, or top of the combustion chamber, is made in the form of a cone with a rounded apex, as shown by the dotted lines. In order to make the interior part of these extra heating surfaces available, it is necessary that the air should flow inwards between the pipes *p*, and pass upwards between the hot surface of the dome and the inside of the annular flue *n*. But if the space between the casing and the outside of the flue is unrestricted, as shown in the figure, there will be nothing to prevent the air from passing up that route, and only a small portion of it will flow up over the dome. The greater part of the air-current will take the path of least resistance and follow the inside of the casing directly to the outlets, unless this airway is throttled by a baffle-plate around *n*.

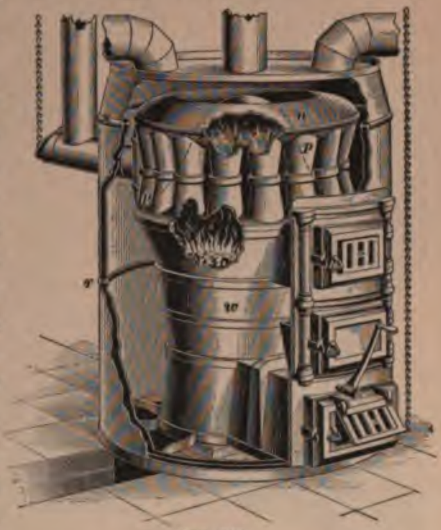

FIG. 748.

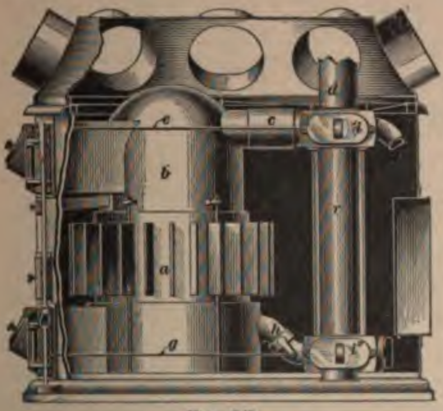

FIG. 749.

1848. The furnace shown in Fig. 749 employs a vertical tubular radiator *r* (shown in perspective in Fig. 750), in addition to the heating surfaces afforded by the ordinary fire-pot *a* and combustion chamber *b*. The hot gases enter the radiator at the top through a flue *c* and pass downwards inside the radiator tubes to the base, from which they escape to the smoke-pipe *d*. The air, of course, moves in the contrary direction; this is necessary in order to secure the most effective heating. A direct-draft damper, which is operated by the rod *e*, is placed inside the casting *f*, Fig. 750, between the smoke-pipe and the top of the radiator, so as to secure a direct draft to the chimney when desired. An ash-pit damper, which is operated by a rod *g*, is placed in the dust-pipe *h*, this latter joining the ash pit to the base of the radiator. This damper is opened only when the fire is being cleaned or the ashes removed from under it, to allow the dust to be drawn into the chimney instead of into the cellar. Handholes are placed at *i*, *i'*, *i''*, *i'''*, Figs. 749 and 750, for cleaning-out purposes, and are accessible through handholes placed in the casing. The general arrangement of this furnace, however, is very defective, because there is so much space between the parts that a large portion of the air is likely to pass through without coming in contact with the heating surfaces and being properly warmed.

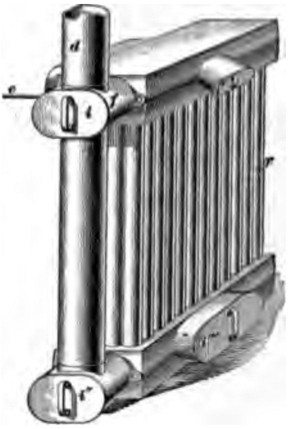

FIG. 750.

1849. In Fig. 751 are shown vertical and cross sections of a furnace which may be taken as a good example of the proper mode of applying vertical heating-tubes to hot-air furnaces. This furnace is designed especially for the use of gas as fuel. Any kind of gas may be used, such as coal gas, water gas, producer gas, or carbureted air, and the fire chamber may also be adapted to burn coal, if desired. The gas is burned in a large atmospheric burner *a*, and the products of combustion pass upwards through the chamber *b*, into the head *c*, thence over into the vertical pipes or drop-flues *g*, *g*, and down through them into the annular flue *h*, from which they escape into the chimney.

Of course, the direct-draft damper *c* must be closed, otherwise the hot gases will flow directly up the chimney, and the drop-flues *g*, *g* will then remain cold. The cross-section of the furnace (shown in the upper view) is taken partly on the line *x x*, and partly on the line *y y* (through the head *e*) as shown in the vertical section. It will be seen that the drop-flues are star shaped in section, and that the combustion chamber is provided with a large number of ribs, or "extended surfaces"; thus the area of heating surface presented to the air is made very large. The air enters at the bottom of the casing in the usual manner, and flows upwards around the tubes, encountering surfaces of successively higher temperatures as it rises, and finally passes up through the slots or channels *f* in the head, as shown by dotted arrows. All the surfaces of the head are very hot, because they receive the direct impact of the column of hot gas and flame arising from the fire-pot; and, as the slots are very narrow, the air is compelled to pass through in thin sheets. Thus, the heating of the air is accomplished in an effective manner, and so much heat is abstracted from the products of combustion that they are discharged into the chimney at a comparatively low temperature.

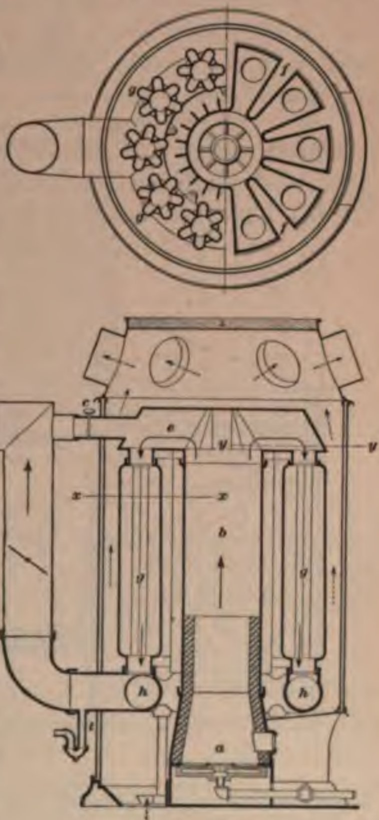

FIG. 751.

When gas is burned in this furnace it is unnecessary to employ a regular chimney, no strong draft is required, and the smoke-pipe may discharge at any convenient point above the level of the heater where the gases will not be offensive. The hydrogen contained in the gas, by combining with oxygen, is converted into water, and this is condensed and deposited in the annular flue *h*, from which it is drained off by the pipe and trap *t*.

1850. Figs. 752 and 753 show a furnace which is designed for use in the larger kinds of buildings, such as shops, schools, churches, etc. In principle it resembles a tubular boiler, the hot gases being conveyed through the air chambers inside tubes of comparatively small diameter. Fig. 752 is a vertical section parallel with the front, and Fig. 753 is a horizontal section on the line *X X*. The fire-box is located in the middle of the structure and is surrounded by the air-heating chambers. The products of combustion pass to the rear over the bridgewall *d*, and flow to the right and left into the combustion chambers *l*, *l'*. From these they pass through the upper sets of tubes *a*, *a'* into the front chambers *n*, *n'*, and return through the lower tubes *b*, *b'* to

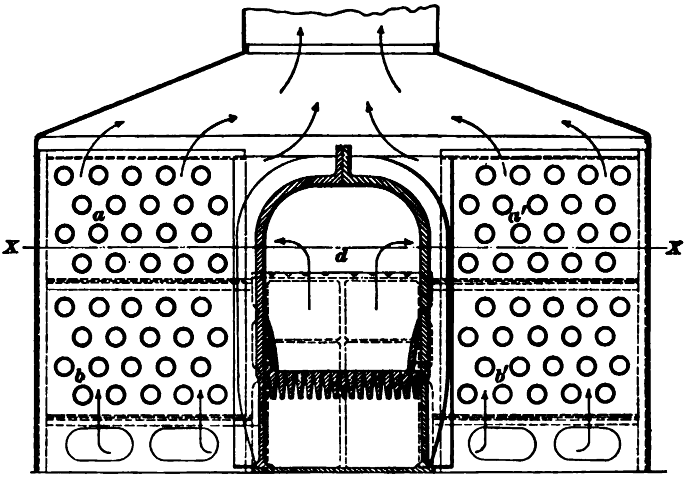

FIG. 752.

flues at the rear, which finally conduct them to the chimney *c*. The air enters at the bottom of the casing and flows upwards between the tubes, and passes off at the top through the large central flue. The tubes are secured to the tube-sheets in such a manner as to permit any tube to be readily removed by means of a common wrench, when burned or clogged.

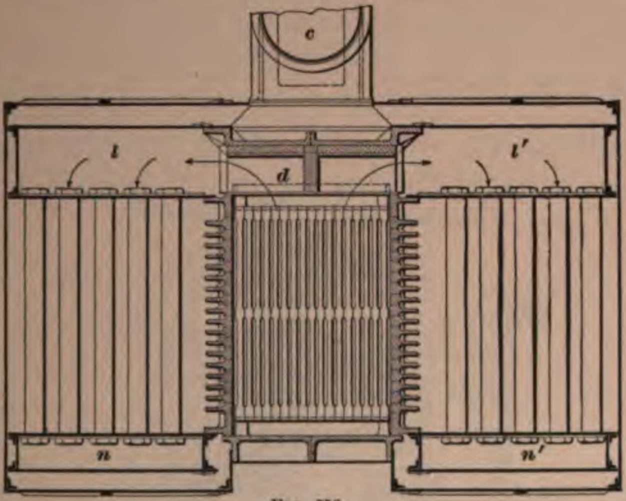

FIG. 753.

1851. In furnaces like Figs. 746, 747, and 748, the lower part of the space within the casing is useless for heating purposes, because the ash pit is cold and emits no heat. This space, however, can be utilized by means of the device shown in Fig. 755. The hot gases are taken downwards from the combustion chamber through vertical pipes *g* into a large annular flue *h*, which carries them around to the rear before discharging them into the smoke-pipe. This flue is located near the base, where it can advantageously impart heat to the incoming fresh air, thus constituting a valuable addition to the area of heating surface, and increasing the vertical height of the hot-air column, which, in turn, increases the velocity of the air through the heater.

COMBINATION HEATERS.

1852. These heaters are the same in construction as ordinary hot-air furnaces, except that they are provided with extra parts, which serve to heat water in sufficient quantity to supply a small number of radiators.

Fig. 754 shows two **water-heaters** which are designed for use in the furnace shown in Fig. 748. The water dome *a* is designed to occupy the upper part of the combustion chamber, and is so shaped as to leave an inch or two of space between it and the gas dome, for the circulation of the hot gases. The inner shell *b* is bell-shaped in order to secure the greatest practicable amount of heating surface.

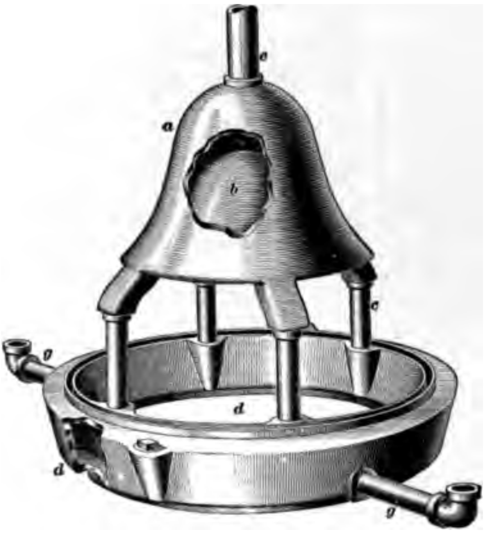

FIG. 754.

The water ring *d* is so constructed that it may be substituted for the ring *w* in Fig. 748. In that case it forms a part of the fire-pot, and receives its heat directly from the mass of glowing fuel. The water dome and the water ring are used separately or in combination, as desired. When combined, they are connected by means of short vertical tubes *c*, as shown. The flow-pipe is connected to the top of the dome at *e*, and the return-pipes are connected to the ring at *g*.

1853. The water heater shown in Fig. 755 consists of three thin flat sections *a* suspended horizontally in the interior of the combustion chamber. These are connected by suitable nipples, and the arrangement of the flow and return pipes is clearly shown in the cut.

In making a selection of a combination heater, particular regard should be paid to the construction of the hot-water heater. This is usually of small dimensions and is liable to have small contracted passageways, or small connections, which make it unfit for hot-water service. Any heater which involves the exposure of screwed pipe-joints or fittings to the direct action of the fire should be avoided.

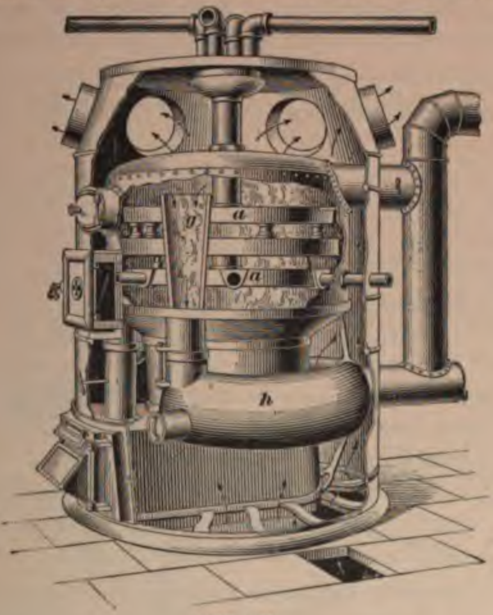

FIG. 755.

1854. Water heaters for combination furnaces may be divided into two classes: those which are exposed only to hot gases, such as *a* in Fig. 755, and those which come into direct contact with the burning fuel, as *d* in Fig. 754. The latter class, when in operation, soon become separated from the live coal by a layer of ashes or dead coal; this retards the transmission of heat and greatly decreases the efficiency of the heater. The former class are free from this defect, but, on the other hand, some varieties are liable to have their usefulness impaired by accumulations of ashes and soot.

FURNACE DETAILS.

1855. A hot-air furnace is composed of many parts, having different functions, and in order for the furnace to work satisfactorily it is essential that each part be properly constructed. The various parts, therefore, will be considered in detail.

The object of enclosing a furnace in a jacket, or casing, is to confine the current of fresh air and compel it to pass over the heating surfaces in a proper manner, and also to prevent waste of heat.

1856. Single Jackets are composed of a single thickness of sheet metal, and are usually lined with a layer of non-conducting material, such as asbestos paper. Sometimes they are lined with bright tin, for the purpose of reflecting back into the interior the heat radiated from the hot parts of the furnace. The reflecting power of the tin is soon reduced to a low degree by deposits of dust which form a coating over its surface, and consequently the economy that can be effected by its use is very small.

1857. Double Jackets are made with an air space of about an inch between the inner and the outer sheet. The edges of the sheets are confined by means of flanged cast-iron rings, such as shown at *r* and *s* in Fig. 748. These rings also serve to stiffen the jacket and keep it in proper shape. For the purpose of retaining the heat, a double jacket having the space between its walls filled with good non-conducting material is much superior to a single jacket; but the best device for this purpose is a double jacket having a circulation of air through its interior spaces. This circulation is obtained by making a number of small holes in the inner wall of the jacket, both at bottom and top, and also making similar holes through the horizontal part of the intermediate jacket rings. Cold fresh air enters the bottom holes and flows upwards between the walls. The passage of heat from the inner to the outer wall is thoroughly prevented by this air-current, because the heat is absorbed by the air-current. The air thus warmed escapes through the top holes and joins the main current. The quantity of air passing through is sufficient to keep the temperature of the outer casing quite low, but is not large enough to appreciably diminish the temperature of the main current.

1858. The **bonnet** is the top part of the furnace casing into which the hot-air pipes are connected, as indicated by *f* in Fig. 746. They are made in many ways, but the shape is generally controlled by the manner in which the pipe connections are made. In Figs. 746, 751, and 755, the sides of the bonnet are made conical, so that the pipes may be connected without an elbow or bend, while in Fig. 756 the sides are made straight and the pipes are connected into the top. This style of connection requires a greater height under the ceiling than the other, and its only advantage lies in the fact that the several connections may be made at equal spaces around the top of the furnace without regard to the direction in which the pipes are to be run, thus taking the air evenly from all sides of the furnace.

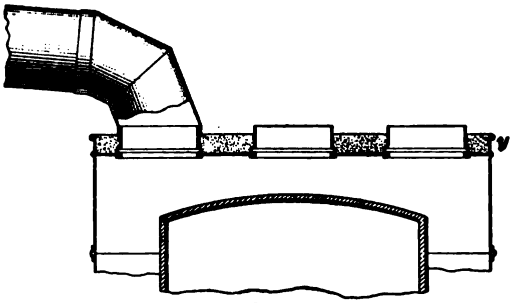

FIG. 756.

1859. In Figs. 751 and 756, the top of the bonnet is provided with a standing rim marked respectively *z* and *y*. This is sometimes called a **sand ring,** and its purpose is to hold a layer of sand, loam, or mineral wool, etc., upon the top of the bonnet for the purpose not only of retaining heat, but of preventing the radiation of an undue or dangerous amount of heat towards the ceiling in case the furnace should become overheated. This layer should be about two inches thick.

The construction shown in Fig. 757 is sometimes used for the same purpose. The top sheet *a* is made conical, or dished downwards, and is covered with non-conducting material in the same way. But it is a very poor substitute for the sand ring, because the covering is likely to be very thin at the edges, and therefore of no value as a non-conductor.

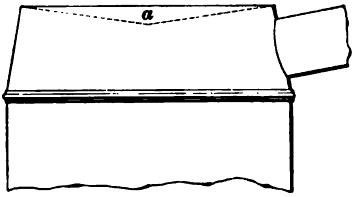

FIG. 757.

The distance between the top sheet of the bonnet and the top of the gas dome or combustion chamber should be from 8 to 12 inches, or more; and it should never under any circumstances be less than 6 inches, because of the danger of becoming overheated, and of choking the air passage too much.

1860. Grates for use in hot-air furnaces are made in a great variety of forms, which differ greatly in the qualities of convenience and durability. The requisites of a good grate are that it shall clear the fire of ashes in a thorough manner, without loss of unburned fuel, and without the escape of dust into the room or into the fresh-air passages of the furnace. It should operate rapidly and should require very little exertion on the part of the attendant.

1861. Fixed grates should never be used, because they afford no facilities for cleaning the fire or for removing the refuse when the fire has gone out. The fire can be cleaned only by the use of a poker thrust up through the grate, and by a clinker bar which is pushed through a poke-hole in the base of the fire-pot. This is the dirtiest and least convenient arrangement that is in use.

Fixed grates may be improved somewhat by making the central part removable, as in Fig. 758. The center grate *a* is attached to the bar *b*, and can slide forwards far enough to uncover the central opening in the main grate *d*. This permits the easy removal of large clinkers or the refuse from a dead fire.

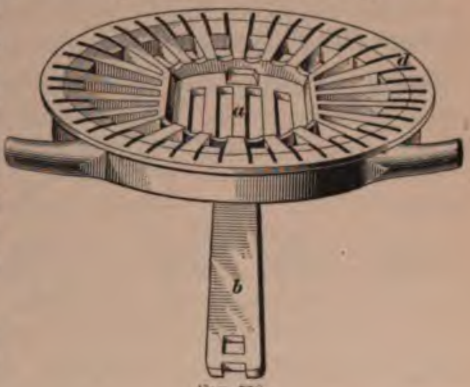

FIG. 758.

1862. Shaking Grates. — Round grates are often made movable, for the purpose of agitating the fire and cleaning it. Some are constructed to vibrate back and forth on a central pivot, and others are provided with a crank and suitable gearing by which they can be rotated to any extent desired. These devices operate very imperfectly, however, because the movement at the center of the grate is too small to be of any use, and because the motion fails to properly agitate the mass of fuel and dislodge the fine ashes which choke the heart of the fire.

1863. A **revolving-bar grate** is shown in Fig. 759. It is composed of a series of revolvable parallel bars having lateral fingers or lugs, which support the fire and constitute a grate surface. Each bar is provided with three sets of fingers, and is supported at the front and rear ends in bearings which permit it to revolve. The whole group is revolved simultaneously by means of the gearing shown. The fingers not only

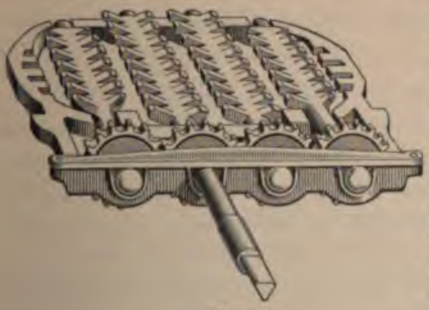
FIG. 759.

shake up and agitate the coal as the bars revolve, but they also break up the bed of ashes which forms at the bottom of the fire and grind up the clinkers, so that they will pass through into the ash pit.

1864. These grates have one defect which, in many cases, is a serious one. The normal position of the bars is shown in Fig. 760, and Fig. 761 shows the positions which are assumed by them in revolving. At the same time that the bars *a* and *b* are nearly touching, point to point, a wide space is opened between *b* and *c*. This opening occurs between each pair of bars when they are merely rocked 30° each way from the normal position. The live coal is very apt to run down through these openings into the ash pit, and thus cause a considerable waste of fuel. When the bars are in their normal position, as in Fig. 760, the points are separated so far that the smaller sizes of anthracite coal, called "chestnut" and "pea," can not be used without excessive waste. Much annoyance is likely to be caused by the live coal falling through into the ash pit in large quantities, thus spoiling the fire, and in many cases ruining the grate.

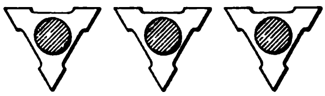

FIG. 760.

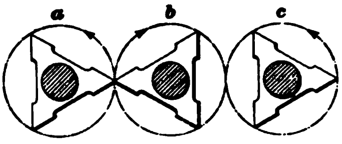

FIG. 761.

1865. Fire-Pots.—The requirements of a fire-pot are that it shall endure steady service for a long time without becoming seriously distorted or cracked, and that it shall be gas-tight. In practice, a fire-pot is subjected to much higher heat in the middle than at either end, and the metal composing it is thus expanded unequally. This results, after a time, in bulging the pot or cracking it.

To prevent this trouble, many manufacturers corrugate the walls of the pot, believing that the corrugations afford some elasticity, which will permit the unequal expansion to take place without damage. This expedient, however, is of no use unless the corrugations are made very deep—much deeper, in fact, than can be conveniently employed in practice.

Another method of providing for the expansion is shown in Fig. 748. The fire-pot is made in two sections, the joint being at about the middle of its height. This construction permits each section to expand independently, and thus relieves the parts from destructive strains to an extent which renders them more durable than the one-piece fire-pot.

Fire-pots are sometimes provided with vertical ribs upon the outside, for the purpose of strengthening them, as shown in Fig. 749, but they add very little to the enduring capacity of the pots, and are valuable only as extensions of the heating surface.

1866. The fire-pot in a hot-air furnace should be made cylindrical rather than conical. If the pot tapers very much, the grate is apt to be too small to maintain good combustion. Although it may be large enough theoretically, the formation of ashes in the interstices of the fuel soon clogs the supply of air and reduces it below the proper amount. The ashes also accumulate upon the sloping sides of the pot and are not easily dislodged by shaking the grate. In a cylindrical pot, the whole fire sinks down readily and uniformly when the grate is shaken, but in a conical pot the fire tends to hang upon the sides and bridge over the grate, making it necessary to poke the fire from the top in order to bring it down.

1867. Linings.—An unlined fire-pot emits a large amount of heat from its outer surface, causing the fuel which touches its inner surface to be cooled below the point of ignition. Consequently, it is usually covered upon the inside by a layer of ashes or dead fuel. If the pot is lined with firebrick, the interior surface of the lining will become incandescent, or nearly so, and the amount of heat transmitted to the outside will be much less than in the case of the unlined pot. The heat thus retained serves to augment the temperature of the fire and promote good combustion.

When a firebrick lining of proper thickness is used, it becomes practicable to construct the fire-pot of steel or wrought-iron plate, and thus secure a pot which is gas-tight.

Plates of cast iron are sometimes used for linings, but under all ordinary circumstances they deteriorate very rapidly, and should therefore be avoided.

1868. Joints.—The first requirement of a joint in a hot-air furnace is that it shall be gas-tight. Unfortunately, it is difficult to make such joints without an amount of labor and expense that is practically prohibitory. In order to make a joint really gas-tight, it must be made with the same care and in the same manner as a joint in an iron steam or water pipe.

1869. Flanged joints must be faced true, and bolted together, with asbestos packing between the parts. **Socket joints** must be filled with rust cement and calked. These forms of joints are seldom used, however, in hot-air furnaces, but they are the only ones, except riveted joints, which can be made properly gas-tight.

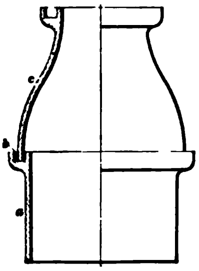

FIG. 762.

The kind of joint which is generally used to connect the parts of a furnace is that shown in Fig. 762. This is called a **cup joint.** The lower piece *a* is constructed with a deep groove around its upper edge at *b*, which is wide enough to admit the lower edge of the piece *c* and also some cement or packing. These joints are usually packed with asbestos cement, but sometimes they are filled only with sand or clay.

Joints which are packed with sand are practically useless for restraining the passage of hot gas. While the sand will prevent the gas from rushing through in a stream, the gas will nevertheless "soak" into the joint on one side and "ooze" out on the other, just as water would do under similar circumstances.

If the metallic parts are cemented together by any cement which will "set" hard and not yield with the unequal expansion of the parts, the joints will soon crack and openings will be formed through which the furnace gases can escape and mix with the hot air which rises up through the hot-air pipes and enters the rooms. In this way, the air in the rooms may become poisoned.

1870. Leakage of Gas.—Gases, like other fluids, will always flow towards the point of lowest pressure. As long as the chimney draft is greater than the draft in the warm-air pipes, the pressure in the jacket of the furnace will exceed that in the combustion chamber, and the air, consequently, will leak inwards through every open joint or crevice in the fire-pot or combustion chamber. But if the chimney draft is weak, and the draft of the warm-air pipes is good, or if the furnace feed door is open, then the pressure will be highest in the combustion chamber, and the gases of combustion will ooze out through every crack or pore-hole in the envelope which separates the products of combustion from the fresh air, and will thus contaminate the fresh-air supply. The poorer the chimney draft, the worse will be the contamination of the fresh air.

Thus it appears that, as long as poor joints exist in a hot-air furnace, security against the leakage of gas into the fresh-air supply depends wholly upon having a better draft in the chimney pipe than in the warm-air pipes. In practice, the force of the chimney draft is subject to great variations. It is diminished by damp, muggy weather, and by the wind blowing down the chimney; but the greatest reduction occurs when the feed-door or the back-draft damper is opened for the purpose of checking the fire. At such times, the pressure in the combustion chamber usually exceeds that in the jacket, and the gas accordingly leaks out and causes headaches and otherwise distresses the occupants of the building.

1871. There is another source of gas leakage which is quite serious, that is, *the passage of carbon monoxide* through the walls of the fire-pot and combustion chamber, which are usually made of cast iron. Unfortunately, this metal is permeable to carbon monoxide, which is a very poisonous gas. At moderate temperatures the amount of carbon monoxide which can filter through is trifling, but at red heat it soaks through the metal quite rapidly. This kind of leakage goes on constantly, with very little regard to the variations in the draft pressure. Cast iron, therefore, is not a proper material for the construction of any part of an air-heater which is liable to become red hot. Metal which has undergone the process of rolling, such as steel and wrought-iron plates, is impervious to these gases at all temperatures.

In order to make really gas-tight furnaces, it is necessary to abandon the use of cast-iron fire-pots and combustion chambers, and to construct of iron or steel plates all the parts which enclose the fire or the gases of combustion. The joints must be as few in number as possible, and should be riveted and calked wherever practicable. A furnace which will not hold *water* without leakage through the joints will not be gas-tight.

1872. Direct Draft.—The direct draft is merely a "by-pass," by means of which the products of combustion may pass directly to the chimney without passing over the usual heating surfaces. It is usually connected at the top of the combustion chamber and is controlled by a damper.

It is chiefly used when making a new fire or starting up a sluggish one, being kept open until the fire has attained a good start. It should always be opened previous to opening the feed-door, in order to prevent the gases of combustion from flowing out into the room. In many furnaces the draft is so poor that carbon monoxide exists in the combustion chamber in considerable quantities. If the feed-door is opened, thus permitting air to enter freely, an explosion of greater or less violence is likely to follow. These explosions frequently burn the face of the attendant and do other serious damage. If the gas is permitted to escape by opening the direct draft for a moment before the door is opened, the danger will become less.

1873. Smoke-Pipes.—The soot which is deposited in the smoke-pipes is strongly acid in its composition, and consequently destroys the pipes in a comparatively short time. In order to withstand the corrosion for a reasonable length of time, the smoke-pipe should be made of galvanized iron, of a thickness not less than No. 20 gauge. There is no good reason, however, why these pipes should not be made of cast iron, like the other parts of the furnace flues. Smoke-pipes should always be short, and long horizontal runs, particularly, should be avoided.

1874. Water-Pans.—These are used for the purpose of adding moisture to the air which is heated by the furnace. They are usually placed on the inside of the jacket, and are mounted in a tilting frame or door so that they can be readily filled or removed for cleaning. The inner surface of the pan should be galvanized or enameled; if left plain it will rust very rapidly and will have to be frequently cleaned. The frame or door to which it is attached should be made to close air-tight, in order to prevent the entrance of cellar air into the jacket. The pans should be located where the fresh air passing through the furnace can easily absorb some of the water, and they should be provided with sliding covers so arranged that the exposed surface of the water may be increased or decreased to suit the requirements of the air.

1875. Magazines.—The purpose of a magazine is to hold a supply of coal and enable the fire to burn for a comparatively long time without replenishing. In many cases this is a great convenience, but the drawbacks attending the use of magazines are so many that their utility in hot-air furnaces is very doubtful.

The coal contained in the ordinary magazine is heated for a long time before it descends into the fire, and this causes it to give off large quantities of gas. This gas consists principally of carbon monoxide, and nearly all of it escapes through the vent-holes at the top of the chamber, and passes off to the chimney without being burned, thus causing a great waste of fuel. The presence of this gas in a hot-air furnace is particularly objectionable, because of its very poisonous character, and the probability that it will leak through into the warm-air passages and poison the air supplied to the house.

Magazines, therefore, are seldom used in *hot-air furnaces.* They are commonly employed, however, in steam and hot-water boilers, when the convenience that they afford is of more importance than the waste of fuel which attends their use.

1876. There are two ways of **regulating the draft** and thereby controlling the intensity of the fire in hot-air furnaces, both of which methods are in common use and are usually combined. One method is to vary the amount of fresh air admitted to the fire, and the other is to admit air above the fire or into the smoke-pipe. The latter method should be prohibited, notwithstanding the fact that it is in general use, because it results in the leakage of gas into the fresh-air passages, as explained in Art. **1870.**

Every furnace should be able to maintain a slow fire, with the direct draft wide open, by closing the ash-pit damper and shutting off all other inlets of fresh air. If the fire can not be sufficiently restrained by these means, it plainly shows that the joints around the doors or ash pit are much too loose and leaky, or else the joints around the fire-pot and combustion chamber admit air in considerable quantities, and are, therefore, not gas-tight; when this is the case they are unfit for use.

The draft may be controlled automatically by employing thermostats in the various rooms and providing them with suitable connections to the dampers.

LOCATION OF A FURNACE.

1877. The location of a furnace is governed principally by the situation or exposure of the house and the location of the chimney. In all the rooms upon those sides of the house which are exposed to the prevailing winds, the temperature will be found to be lower and the air pressure higher than in other parts of the house. The increase of air pressure in these rooms makes it necessary that the hot air in the flues leading to them should have the highest practicable temperature and pressure, in order to flow into the rooms in sufficient quantity. These flues must, therefore, be connected to the furnace with the least possible length of horizontal piping, and, consequently, the proper place for the furnace is near the exposed, or coldest, sides of the house.

The work should be so planned that all long horizontal pipes will be connected only to the tallest vertical flues, and that only short ones will be employed to serve registers on the first floor. The furnace should be located as central as possible, with all due consideration for exposures.

1878. Great care should be taken to avoid setting up the furnace over a drain pipe of any kind. Even a well-made iron-pipe drain is so liable to be broken or made leaky by the weight of the furnace that it must not be permitted to run under it. A drain of earthen or fireclay pipes should never, on any account, be permitted to exist in the cellar of any dwelling. If a furnace must be erected in a cellar having such a drain running through it, it must be kept as far away from the drain as possible. The fireclay pipes should be removed and replaced by a well-made iron-pipe drain, and all ground which betrays any foul odor should be removed and replaced by fresh earth or ashes. This is a matter on which there should be no compromise or shirking. Drains made of fireclay pipes *always* leak, and are always a prolific source of danger and disease. If there is any suspicion of drain air or sewer gas entering the building through the hot-air apparatus, the furnace man should acquaint the owner of it and ask him to order his plumber to put a smoke test on the drainage system. If there are any defects, the smoke will flow up through the hot-air flues and enter the rooms, where it may either be seen or else detected by its odor.

FOUNDATIONS AND SETTINGS.

1879. A hot-air furnace should be set at the lowest practicable level, so that even the longest horizontal hot-air pipe may be given a sufficient upward inclination to make it operate well. (See Art. **1891.**) In some cases the ceiling of the basement is so low that it is necessary to set the furnace in a pit. The extreme top of the furnace casing should never be less than 18 inches below the ceiling or floor beams, and should be as much more below it as possible.

The pit, if one be required, should be made large enough to afford plenty of standing room for the person who attends to the fire, and to permit the free use of the poker and the shovel when removing ashes. The side walls of the pit should be 8 inches thick if made of brick, and 12 inches or more if made of stone. The bottom should be covered with one course of brick on edge, or with concrete at least 4 inches deep, or, better still, with flagstones.

Foundations should never be built in *frozen ground*, because the ground will inevitably sink when it thaws, and will probably crack the masonry and throw it out of level.

1880. Portable Settings. — Fig. 763 shows the proper method of constructing a foundation for an ordinary portable furnace, the cold air being taken in below the floor level, through the cold-air box *a*. Having decided upon the location of the furnace, and the direction in which it should face, the center should be marked upon the ceiling. A

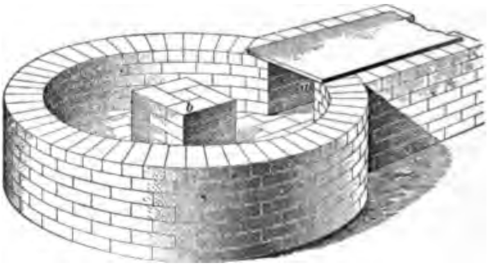

FIG. 763.

plumb-line may then be dropped from this point to guide the operations of digging and brick-laying.

The outer wall should be 8 inches thick, and its diameter, measured upon the inside, should be just equal to the inner diameter of the base ring upon which the casing stands. At the center of the pit, a brick pier *b* should be built, 12 inches square. Care should be taken to level the top of the wall all the way round, and to bring the top of the pier to exactly the same level. The bottom of the pit thus enclosed should be lined with brick or concrete, and should always be made water-tight. The height of the pit above the bottom should be from 12 to 16 inches, according to the size of the furnace.

The opening *a* for the entrance of cold air may be made at any part of the circle. If it is made at the front, however, so that it comes under the ash door, great care must be taken to make the covering plates strong and perfectly tight against the entrance of dust.

If the cold air is to enter the casing above the level of the floor, the foundation need not be made so deep; in fact, some furnaces are so constructed as to require no pit under them.

1881. Brick Settings.—In this construction, the furnace is surrounded by two brick walls *a* and *b*, as shown in Fig. 764. The inner wall *a* is circular and is made of the same diameter internally as the jacket of an ordinary portable setting. The outer wall *b* is made square, and a clear space is left between them of about 2 inches at the narrowest parts.

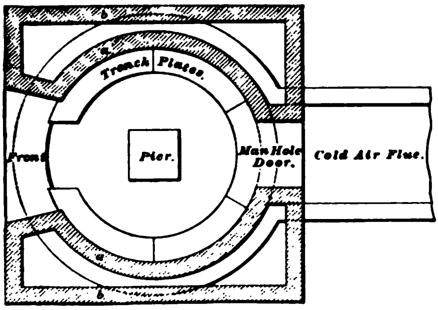

FIG. 764.

The circular foundation-wall and central pier are built in the same manner as before described, the diameter being prescribed by the maker of the furnace. The parts of the furnace are then set up in place, and the frames for the various doors are set up plumb, according to the plans or catalogue cuts furnished by the makers. The cold-air trench is covered with iron plates suitable for supporting the walls where they cross it. The inner and outer walls are then carried up together to the level of the dome or main heating chamber of the furnace. Each wall should be 4 inches thick. The inner wall should be plastered smooth on its inner face, and the joints in the outer wall should be well pointed to close all crevices and present a good appearance.

The hot-air pipes should then be placed in position, bringing the ends flush with the inner surface of the inner wall, and the *tops* of the pipes should all be brought to the same level, regardless of their diameters. The walls should then be carried up to at least one course above the tops of the pipes. The covering bars may then be put in position, placing them not less than 12 inches above the highest part of the furnace. The joints between the bars should be covered with tin, and the top may then be completed by laying over the whole structure two flat courses of brick in mortar.

The foundation under the square wall is usually made of one course of brick, laid flat and flush with the top of the circular foundation wall.

1882. In order to compel the fresh air to pass close to the sides of the fire-pot, a set of deflecting plates, commonly called **trench plates**, are set up inside the inner chamber, at about the level of the top of the ash pit, as shown. The best manner of supporting them is to imbed their outer edges in the circular wall to a depth of about one or two inches.

The smoke-pipe should be conducted through a "wall pipe" or thimble of cast iron, which extends through both walls. The outer end of this thimble should be carefully closed so as to prevent the entrance of cellar air.

The space between the outer and inner walls is useful only as forming a non-conductor of heat. It should be connected to the inner chamber by one or two small holes at the bottom and top, but no communication with the outer air should be permitted. Every door or cleaning hole in the outer wall should be made air-tight.

Brick settings occupy more space than portable ones, and have no advantage over them, except that the escape of heat is more effectively prevented. The double jacket employed in portable settings, which is constructed with double walls and has a small air-current flowing up between them, as previously described, is nearly as good an interceptor of heat as the brick setting, and if the bonnet is well protected on the top and sides with non-conducting material, the portable setting may be made as efficient in every respect as the brick setting.

SETTING UP A FURNACE.

1883. The base ring of the furnace should be laid in cement and made tight at all points, so that no air can pass under it. It must also be carefully leveled, so that the casings and other parts will stand *plumb*. The center of the grate should be made to come exactly under the center mark on the ceiling.

In setting up the castings, care should be taken to see that each horizontal joint is level both ways, and that the face of each door frame is plumb. If this is neglected, the doors are likely to give trouble by swinging open of themselves, or by refusing to stand open when desired. Every joint should be carefully cemented and made as nearly gas-tight as possible.

In putting on the jacket, every joint should be made proof against the entrance of cellar air, and every door frame and cleaning-hole ring must be carefully packed for the same reason.

The smoke-pipe must be fitted tightly to the collar on the combustion chamber or flue. Corrosion is very liable to occur at this place and thus cause a leakage of gas; close attention should therefore be given to this matter. The

chimney should be examined before the smoke-pipe is attached to it, to see that it is unobstructed and in good order. Before lighting a fire in the furnace, the vent or cleaning holes at the base of the chimney should be closed.

AIR SUPPLY AND DISTRIBUTION.

COLD-AIR SUPPLY.

1884. The furnace should be supplied with fresh air by means of a duct, which has an inlet at some point above ground upon the windy side of the house. This inlet, or **cold-air box,** as it is often called, must always be on that side of the house where the air pressure is highest; if it opens to the leeward side, the warm air in the furnace is very liable to be driven down through the cold-air flue and discharged out of doors.

If strong winds are likely to blow from various directions, the cold-air duct should have inlets at the several exposed sides of the building. Each inlet must be provided with a damper, or other closing device, so that all may be shut off except the one which faces the wind.

Cold-air inlet openings should always be made high enough above the ground to prevent surface water from entering them, and they should be covered with wire netting to keep out animals, etc. The higher the inlet can be made, without reversing the current, the better, because the air near the ground is always of inferior quality, compared with that two or three feet above it.

The cold-air duct should always be made air-tight, so that no air can enter the furnace from the cellar. No part of the duct should be open to the ground, because "ground air" is always unsuitable air to breathe. The common method of constructing a cold-air duct in the ground, which consists in building two small walls of brick along the sides of a trench having an earth bottom, and covering the trench with flagstones or planking, is a very bad one and should not be permitted unless the bottom of the trench is made water-tight. The worst arrangement, however, is a similar duct having wooden sides and top. The wood slowly rots, and the ground air freely enters the duct.

1885. Underground ducts should always be strictly water-tight. A very good method of constructing such a duct is to use a glazed earthenware pipe of sufficient size, cementing each joint as carefully as for a sewage drain. Fig. 765 shows a cold-air duct made in that way, with openings at opposite sides of the building. Two methods are shown of arranging the inlets and dampers. At *a*, the shutter or damper is hinged at one edge to the window frame; and at *b*, an ordinary butterfly damper is employed. The dampers may be operated from the rooms above, if so desired, by means of chain and pulleys.

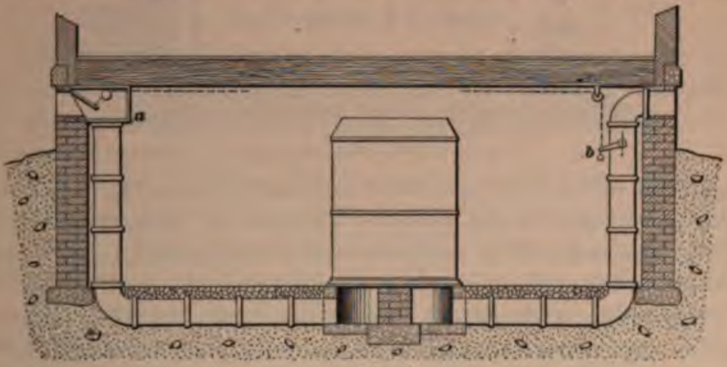

FIG. 765.

No fresh-air inlet for a drainage system should be permitted to exist anywhere in the vicinity of a cold-air inlet for the furnace. Too much care can not be taken in this matter.

The **area** of a cold-air duct should equal $\frac{2}{3}$ or $\frac{3}{4}$ of the aggregate area of all the hot-air pipes.

1886. Inside Cold-Air Ducts.—In heating large rooms, the cold-air supply is sometimes taken through a register in the floor, as shown at *b* in Fig. 766. The air then circulates through the furnace and through the room continuously, without the introduction of any fresh air.

This method is useful only for heating the building when ventilation is not required.

It is used chiefly for warming a large space occupied by very few people. It may also be used for heating a large auditorium before the audience arrives, but as soon as ventilation is required a damper in the inside supply pipe is closed and that in the outside supply pipe *a* is opened.

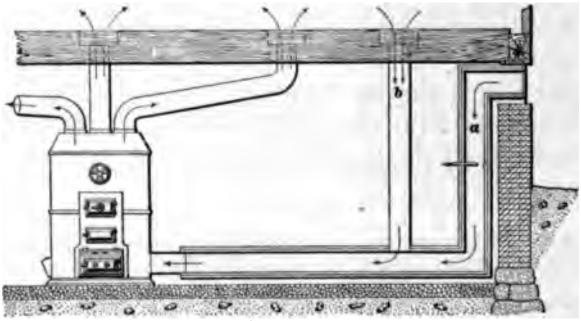

FIG. 766.

When this arrangement is used in private residences, the inside supply register should be located in the front hall and near the front door, if possible.

1887. Automatic Controlling Valve.—In situations where the wind is likely to blow too strongly, and thereby force the air through the cold-air flue in excessive quantities, it is sometimes advisable to use an automatic controlling valve like that shown in Fig. 767. This is called **Arnott's valve,** or, sometimes, a "wind valve." This apparatus consists of a movable screen *a b* which is pivoted over a partition at *c* and carries shutters *d* and *c* at its ends. The section *a* is larger in area than *b*, so that the wind entering at *f* has a tendency to depress it and so close the shutters *d*, *c*, thus diminishing the inlet and also the opening into the cold-air duct at *g*. The balance-weight

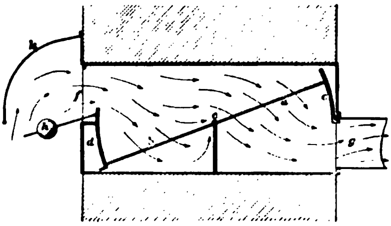

FIG. 767.

h is used to prevent the valve from moving too easily. A cap *k* is provided to keep out the snow. When the wind blows gently against the inlet *f*, the weight *h* is heavy enough to keep the valve open; but when it blows strongly, the excessive pressure on top of *a* partly closes the valve, and consequently prevents an excess of pressure in *g*. Thus, in stormy weather, the pressure in *g* will remain nearly uniform.

HOT-AIR FLUES.

1888. The principles which govern the construction of air conduits and flues have already been clearly explained in the second section on Heating and Ventilation, and only few details remain for consideration here.

The (nearly) horizontal pipes which extend from the furnace to the foot of the vertical flues are sometimes called **leaders.** These should be made with as few joints as possible. Every joint should be soldered or otherwise made air-tight, except the longitudinal seams, which should be lock-seamed.

1889. Slip-joints should not be used, except at points where it may be desirable to disconnect the pipes at some future time. These joints should be made as tight as possible, and should be constructed as shown in Fig. 768. The bead *a* should be about $\frac{1}{8}$ inch deep, and $1\frac{1}{2}$ or 2 inches from the end of the pipe.

The choice of material for hot-air flues should be governed by considerations of durability and cost. They are commonly made of I C or I X bright tin, and it is supposed that the bright surface is of special value as serving to prevent the undue escape of heat from the hot air within them. This supposition, however, is not well grounded. The principal loss of heat is caused by conduction through the metal to the outer air rather than by radiation. A bright surface is useful for diminishing radiation, but has only a slight influence upon conduction.

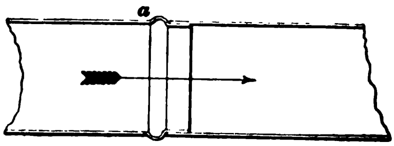

FIG. 768.

All hot-air pipes should be lagged, or covered with non-conducting material, in order to preserve the temperature of the hot air as long as possible, and thus secure the greatest possible draft. In cases where leaders of great length must be used, the draft is very liable to be sluggish, and it is especially important that these pipes be protected from loss of heat. The sluggishness is due partly to friction, but mainly to the cooling of the air and the consequent decrease in its density.

1890. The vertical pipes which are built into the walls and partitions are usually called **stacks.** These are made flat or oval, to suit the spaces through which they must pass. In wooden buildings, a clear space of not less than ½ inch should be provided all around the pipe. This space should be packed with proper non-conducting material, or else the pipe should be wrapped with at least two layers of asbestos paper and bound with wire. Stacks are sometimes made with double walls enclosing an air space between them, the air space being intended to prevent the escape of heat. This construction is quite inferior in that respect to a single pipe well wrapped with non-conductors.

In situations where there is any chance that the pipes may become overheated and possibly set fire to woodwork, pipes with double walls may be used to good advantage. The air space should be provided with openings both at the top and bottom, so that a current of cold air may flow up through and discharge freely at the top in sufficient volume to intercept and carry away the excessive heat escaping at that point. It should be noted, however, that in any properly designed heating system it is not possible that such overheating can occur.

1891. Grading.—All hot-air pipes running horizontally should be given an upward grade of not less than 1 inch per foot, if practicable, and more if convenient. This grade is usually sufficient to overcome the friction of the air in the pipe and secure a reasonably good flow, provided that the temperature is not permitted to fall off during the transit.

DAMPERS.

1892. Every leader should be provided with a damper at a point close to the furnace. The common butterfly damper is good enough for this purpose, if carefully made and fitted. It should be constructed so as to work freely and shut tight enough to completely stop the flow of hot air through the pipe. If the pipe is very large, it should be reenforced with a strong band at the point where the damper is located, in order to keep it in proper shape and thus prevent the damper from binding. The principal use of these dampers is to throttle the air-currents and thus adjust the supply of hot air to the various leaders. A change in the weather or in the direction of the wind frequently makes it necessary to alter the proportional volumes of hot air that are supplied to the several parts of the house, and these dampers afford a convenient means of making the adjustment.

REGISTERS.

1893. This name is commonly used to designate the special opening through which air enters or leaves a room, and it is also applied to the combination of valves and grating which is employed to control the opening.

1894. **Floor registers** are usually constructed and set in position as shown in Fig. 769. They consist of a group

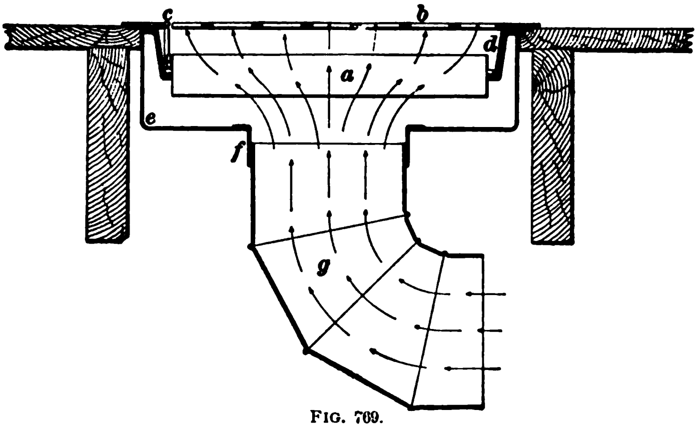

FIG. 769.

of valve plates or "louvres" *a*, which turn on pivots at each end and are operated simultaneously by means of a link connection and a lever *c*. They are supported in an iron frame *d*, and are protected by a stout iron grating or grille *b*, which is made strong enough to be walked upon without injury. **Wall registers** are constructed in practically the same manner.

1895. The ordinary method of setting a floor register is to place it over the top of a shallow box *e*, which is connected to the hot-air pipe *g* by means of a collar *f* at the bottom. This is called a **register box.** The shape illustrated in Fig. 769 represents ordinary practice, but it is nevertheless very defective. As the sole purpose of the box is to connect the pipe to the register, it should be so designed as to offer the least practicable resistance to the flow of the hot air.

The box *e* is much wider than it ought to be, and it is so shallow that the air-current has very little opportunity to spread out before it encounters the louvres. The enlargement is so abrupt that it causes considerable resistance to the flow of the air-current. A better construction is shown in Fig. 770. The box is made deep enough to permit the pipe to be connected without an upward bend. The end *a* is vertical, and the end *b* is inclined to such an extent that the bottom of the box is about half as long as the top. The sides are made flaring, as shown, and the bottom is rounded to match the collar *c*.

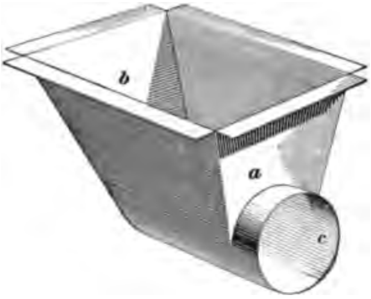

FIG. 770.

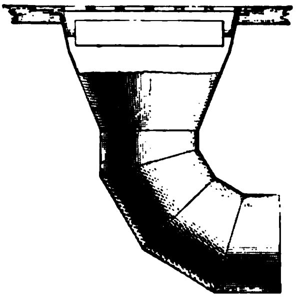

FIG. 771.

The shape shown in Fig. 771 is also a very good one, but it requires more head room than any other, and is, therefore, impracticable in many cases.

1896. Vertical, or wall, register boxes are made in a very simple manner, as illustrated in Fig. 772. The flange *a* around the opening is made long enough to reach about ½ inch beyond the face of the wall. After the walls are plastered or otherwise finished, the corners of *a* are "snipped" with the shears and the projecting part of *a* is bent over the finished face of the wall. The register is then placed in position and is usually held there by common wood screws.

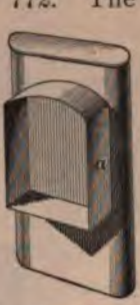

FIG. 772.

1897. A **double register box** is shown in Fig. 773. In this case a single vertical flue supplies hot air to two opposite rooms. The flue is divided by a partition *a*, which extends to a considerable distance below the registers *b*, *b*. This is necessary in order to prevent either register from discharging more than its proper share of the hot air, and also to prevent persons from looking through the registers from one room into the other.

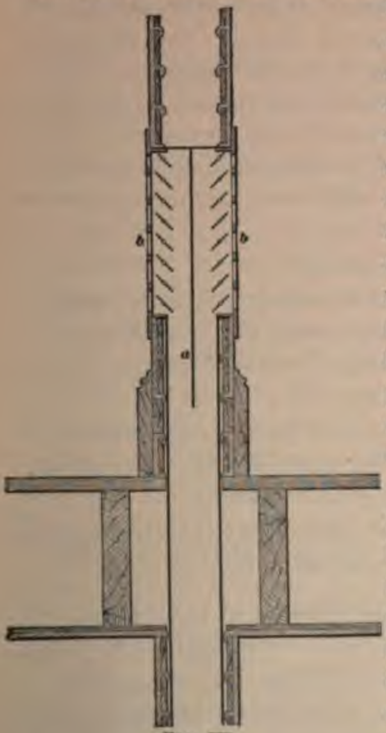

FIG. 773.

Double registers should never be used if they can be avoided. During a great part of the time the air pressure in one of the rooms is likely to be higher than in the other, and the difference will be sufficient in many cases to drive most of the hot air into the other room. Separate flues should always be run to each register.

1898. Register boxes in large wall flues should be rounded over at the top, as shown at *a*, in Fig. 774, and sometimes at the lower edge of the opening also. The openings should be covered with wire netting or grating of ½-inch mesh, or larger, attached to light wrought-iron frames of suitable shape. The cast-iron louvres commonly used in the ordinary floor and wall registers are not suitable for these openings, because they offer too much obstruction to the air-current and are very clumsy. It is better practice to use a butterfly damper to control the air, placing it in the flue at a convenient height, so that it can be operated without the use of cords, etc. The handle should be provided with a clamping device by which the damper may be securely fastened in any position desired.

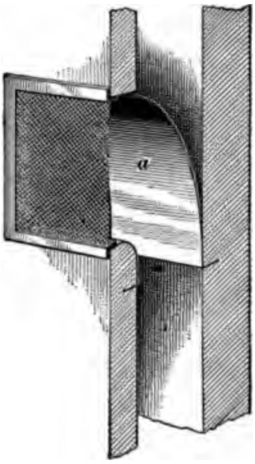

FIG. 774.

SIZE OF PIPES.

1899. It is common practice to proportion the area of the hot-air pipes to the cubical contents of the rooms which they supply. The area of the pipe in square inches may be found by the following

Rule.—*For rooms on the first floor having only a moderate exposure, divide the volume of the room in cubic feet by 30, or by 25 to 20 for rooms having great exposure.*

For second-floor rooms, the divisor may range from 35 to 25, and for third-floor rooms, from 40 to 30.

1900. A more accurate method is to proportion the area of the pipes to the cooling surfaces in the rooms. This may be done by the use of the following

Rule.—*For rooms on the first floor, add together the total glass surface and ¼ of the area of the exposed walls in* *square feet, and multiply the total by 1.5; the product is the proper area of the pipe in square inches. For second-story rooms, multiply by 1 to 1.25, according to the exposure; and for the third story, by .75 to 1.*

The stacks, or wall flues, are usually flattened in form, and cause more friction than the leader pipes, which are usually round. When a stack is connected to a leader of considerable length, the area of the latter should exceed that of the former by 20 to 30 per cent., or even more in extreme cases.

In computing the size of a stack, some allowance must be made if its length in proportion to its area is unusually great. Allowance must also be made for all elbows and offsets. No satisfactory rule can be given for making these allowances; the fitter must carefully consider each case and use his judgment.

In computing the sizes of pipes and registers for ordinary dwellings of small or moderate size, the requirements of ventilation are usually not considered, it being assumed that the amount of air required for heating purposes is also sufficient for ventilation. The error of this assumption, and the mischief which it entails in many cases, will be fully considered in the section on Ventilation.

1901. In all large installations, such as for stores, schools, halls, and churches, the problem of ventilation must be considered first. Having found the quantity of air required per minute, the size of the pipes may be computed by dividing the required volume by the velocity of the air-current. In all ordinary cases this may be safely assumed at 4 feet *per second* at the first floor, 5 feet at the second floor, and 6 feet per second at the third floor.

Another method, equally good, is to assume that *one square inch of stack, or flue, area will supply 100 cubic feet of air per hour at the first floor, 125 at the second, and 150 at the third floor.*

It is assumed in all of the foregoing rules that the average temperature of the hot air in the flues is about 120°, and that the air is moved solely by natural draft.

1902. The following table shows the sizes allowed in common practice for pipes and registers in ordinary dwellings:

TABLE 77.

SIZE OF HOT-AIR PIPES AND REGISTERS.

First-Floor Rooms.				Second-Floor Rooms.			
Size of Register in Inches.	Diam. of Pipe in In.	Size of Rooms in Feet.	Height of Ceiling in Feet.	Size of Register in Inches.	Diam. of Pipe in In.	Size of Rooms in Feet.	Height of Ceiling in Feet.
12×15	12	16×16 to 18×20	11	10×14	10	16×16 to 18×20	10
10×12 or 10×14	10	14×14 to 15×15	10	9×12	9	14×14 to 16×16	9
9×12	9	12×12 to 14×15	9	8×12	8	10×10 to 13×14	8
8×12	8	8×12 to 13×13	9	8×10	7	7×12 to 12×12	8

SIZE OF FURNACE REQUIRED.

1903. In order to estimate the proper size of a furnace for warming any given building, the first proceeding is to compute the probable loss of heat by radiation and conduction from the whole building, in heat units per hour, with the weather at zero, taking into consideration the situation and exposure to wind. The loss by ventilation must be added to the loss by cooling, as fully explained in the second section on Heating and Ventilation. Where no definite ventilation system is employed, as in ordinary dwellings, the total loss from both causes may be computed by multiplying the estimated loss from cooling, in heat units per hour, by 2.18.

The above result is based on the assumption that the hot air enters the room at 120°, and that all of it escapes at a temperature of 65°. In such a case, it is plain that $\frac{65}{120}$ of the total heat supplied by the hot-air current is lost in ventilation, and only the remaining $\frac{55}{120}$ is expended in maintaining the temperature of the room. The total heat used (or, in other words, lost) altogether may be represented by 120, and is therefore $\frac{120}{55}$ or 2.18 times the amount lost by cooling only (i. e., by radiation and conduction).

The next step is to compute the amount of fuel that must be consumed per hour. This may be found by dividing the total estimated loss of heat per hour by the number of heat units that will be given off by each pound of the fuel in burning. See article on Fuel in the second section of Heating and Ventilation.

The furnace, however, will not transfer to the air passing through it all the heat developed by the fuel, but will waste a large portion of it. The coefficient of efficiency of hot-air furnaces ranges from 50 to 60 per cent.; therefore, the estimate of fuel required must be increased 100 to 66 per cent., accordingly.

The rate of combustion per hour in ordinary furnaces averages about 3 pounds of coal per square foot of grate surface. The required grate area in square feet may be found by dividing the proposed fuel consumption in pounds per hour by 3. Thus we arrive at the dimension upon which all others depend—namely, the **area of the grate.**

The area of the heating surfaces should be from 40 to 50 times that of the grate, as previously explained. With a higher rate of combustion, the proportion of heating surface should be increased still more, not, however, in direct proportion to the amount of fuel burned.

GENERAL NOTES.

1904. The application of hot-air furnaces is limited to a radius of about 30 feet, that is, it is impracticable to use a leader pipe more than 30 feet long, except under the most favorable circumstances.

When heat is required at a greater distance than that, it is advisable to use a **combination furnace,** and employ steam or hot-water radiators at those remote points. Radiators may also be used to good advantage in corridors and vestibules, where outside doors are frequently opened and where it is difficult to retain warm air.

In large installations, requiring great quantities of hot air, it is customary to employ several furnaces, set singly or in groups. In many cases, instead of using one large furnace or a group of furnaces centrally located, it is better practice to use a number of independent furnaces. Each single furnace may then be located in a position which will enable it to serve, to the best advantage, the section of the building assigned to it.

1905. When a single central furnace or group is employed, it is found to be very difficult to properly heat the windward side of the building during stormy weather. This is the time, too, when heat is most needed. If independent furnaces are used, the one on the exposed side of the building may be worked at a much higher temperature than usual, in order to secure the stronger draft required in the hot-air flues. Of course, the cold-air supply must be arranged to take full advantage of the wind, and each furnace must be provided with suitable gates or dampers for controlling the inflow of cold air.

The use of independent furnaces involves more labor on the part of the attendant, but in such cases it is better to provide the extra labor than to sacrifice the efficiency of the heating system, and permit it to fail when heat is most needed.

1906. Heating by hot-air furnaces can not be performed successfully on a large scale without taking into full consideration all the circumstances which affect the distribution and diffusion of warm air. The introduction of currents of highly heated air into a room may be either a great aid to ventilation or a serious impediment, according to the manner in which it is managed. The problems of distributing and diffusing air belong properly to the art of ventilation, and will be found fully treated in the section on that subject.

VENTILATION OF BUILDINGS.

QUALITY, QUANTITY, AND PREPARATION OF AIR.

1907. Ventilation may be properly defined as the *systematic* and continuous *removal* of foul air from rooms used either for habitation or for manufacturing purposes, and the constant introduction of fresh air to take its place. To constitute a system of ventilation, these operations must be practically continuous, at least during the time that the premises are occupied by persons or animals. The *occasional* airing of rooms by opening the doors and windows, allowing the fresh outdoor air to enter and dilute or displace the vitiated atmosphere, is called "aeration" merely, and is not considered as coming strictly within the meaning of the term "ventilation."

1908. Ventilating processes are used for many purposes besides the purification of the air in dwellings, etc. They are employed for removing smoke and offensive odors given off during manufacturing operations; to carry away the steam and vapor from drying-rooms and dye-houses; to expel and disperse poisonous or explosive gases, such as are found in coal mining operations; to drive off overheated air, and keep the temperature of rooms down to a proper degree; to prevent sunshine and the heat of the outer atmosphere from penetrating into icehouses or cold rooms, and to maintain a uniform degree of cold and dryness in cold storage warehouses. They are also employed in stables and barns for the use of horses, and, notably, for the benefit of milch cows.

In studying the subject of ventilation, therefore, it is necessary to consider the physical properties of air and gases,

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and the variations in them caused by changes in the weather; the nature, source, and extent of the emanations which contaminate the air and make its removal necessary; the means that are available for moving it in the manner desired, and the apparatus which is best adapted for that purpose; and also the proper manner of arranging and constructing buildings so as to secure good ventilation at all seasons, and at reasonable cost.

The air which is furnished to dwellings, etc., must be thoroughly adapted to the wants of the inmates at all times, being warmed in winter and cooled in summer. It should be regulated as to quantity and humidity, and its purity must be assured under all circumstances. The subject of ventilation, therefore, includes not only the movement and distribution of air, but also the heating, cooling, drying, humidification, and purification which are necessary to fit it for use.

1909. The primary object of ventilation is the *removal* of the vitiated air. This being done, natural air, presumably of better quality, will flow in from all directions to take its place. The preparation of this fresh air for use by warming and otherwise is a secondary matter, although one of great importance.

The need of heat for warming purposes is universally understood, but the necessity of having pure air to breathe is not so well known—indeed, many people, otherwise well informed, regard the demand for pure air as an unnecessary refinement. It may be noted, however, that people can endure great variations in the temperature without injury, merely by adjusting the amount of their clothing, but that they can not breathe foul air without paying the full penalty in every case, and that there is no possible way of adjusting the human organism so as to be unharmed by it.

While all diseases are aggravated by inhaling bad air, it is not known with certainty that any specific disease is directly traceable to its influence. Of course, if the air is infested with disease germs thrown off from persons suffering from smallpox, typhus, cholera, consumption, or other contagious diseases, it will operate to spread these malignant affections by conveying the germs into the mouth and lungs of healthy people.

The evil effects of the habitual breathing of vitiated air, by both men and animals, have been carefully observed for long periods of time. The most noticeable and certain effect is the lowering of the vital energies of persons thus exposed, producing what is called "general debility," and making them very susceptible to disease in all forms. Healthy people possess a high resisting power against disease, but the continued inhalation of impure air constantly diminishes this power of resistance, until the persons thus affected easily succumb to any adverse influence that may be brought to bear upon them. Children have less vital energy than adults, and are more quickly and seriously affected.

1910. Good ventilation is not only desirable for the pleasure which is afforded by breathing fresh, invigorating air, but is also absolutely necessary for the maintenance of good health, and to prevent the spread of infectious diseases. It is highly desirable, also, as a matter of cleanliness. No civilized person will consent to take into his mouth any article of food which has been in the mouth of another, or to put on underclothing which has been worn by some other person. There is precisely the same reason for refusing to inhale the air which has been ejected from the lungs of other people, or to breathe air mingled with the vapor and odors given off from their bodies and clothing.

It can not be said that good ventilation has been attained until each person is supplied with air in proper quantity, of proper temperature, without drafts, and free from all animal exhalations, street dust, gases of decomposition, or products of combustion.

THE VITIATION OF AIR.

1911. Air is rendered unfit for breathing by a great variety of causes, that of respiration being the most conspicuous.

Each adult person breathes about 20 times per minute and inhales about 30 cubic inches of air at each breath. The air on entering the lungs contains about 79 per cent., by volume, of nitrogen, and 20.8 per cent. of oxygen, with a very small fraction of carbonic acid; but when it is expired it contains only about 15.4 per cent. of oxygen, while the carbonic acid is increased to about 4.3 per cent. of the total volume. The quantity of available oxygen is thus reduced from 20.8 parts to 15.4 parts, or very nearly 26 per cent. The statement is commonly made in technical literature that only about 5 per cent. of *the air* is taken up by the lungs and applied to the uses of the body, but this mode of stating the facts is very misleading, because it fails to convey an adequate idea of the extent to which the air is actually impoverished or vitiated.

The oxygen is the only part of the air (excepting the moisture) which serves to sustain life. The nitrogen is wholly useless, being perfectly inert, and is expelled from the lungs without undergoing any change whatever. It is inhaled simply because it is so thoroughly mixed with the oxygen that its inhalation can not be avoided. Only about 21 per cent. of the air is of any use for sustaining life, the remainder merely acting in a mechanical way to dilute the oxygen and increase the volume of the mixture. Air which is breathed once thereby loses 26 per cent. of its oxygen, that is, 26 per cent. of its total life-sustaining power.

1912. A **deficiency of oxygen** can not be long endured by human beings or animals without serious injury, but, on the other hand, an excess of oxygen does no harm unless the excess be very great. It has been shown by experiment that men can live in pure oxygen for an hour or more at a time without any serious inconvenience. The practice of breathing oxygen, either pure or mixed in various degrees, has been employed with considerable success, in recent years, for the cure of certain forms of disease.

If dwelling houses were made really air-tight, the trouble from the vitiation of the air by breathing would soon become intolerable; indeed, it would be difficult to maintain life, after all the air had once been inhaled. Fortunately, however, walls are generally so pervious to oxygen that it makes its way inwards from the outer atmosphere with sufficient rapidity to maintain a fair proportion to the other constituents of the air. This infusion of fresh oxygen, however, may fail to take place in small, dark rooms which are remote from the open air, and in vaults and subterranean rooms. In such cases, the diminution of oxygen may become a very serious matter.

1913. The amount of oxygen consumed per hour varies with the age and state of health of the person, and also with the degree of activity—whether asleep or awake, or engaged in muscular labor. Animals require more oxygen than men.

The amounts of oxygen consumed in equal times, per pound of actual weight (not per head), are in the following proportions:

Man,	100.	Sheep,	117.	Dog,	283.
Horse,	135.	Ox,	132.	Chicken,	312.

The average adult man consumes oxygen at the rate of 20 cubic feet per day, or about 1 cubic foot per hour while engaged in active labor, and less when quiet or asleep.

CARBONIC ACID.

1914. The formation of this gas in the lungs is practically continuous, only a portion being expelled at each breath. The oxygen which is absorbed into the lung cells comes into contact with carbonaceous matter derived from the food, and combination takes place, resulting in the formation of **carbon dioxide,** commonly called carbonic acid, and denoted by the symbol CO_2. This process, in fact, is one of combustion, and is in every respect the same as that which takes place in a furnace, except that it is less intense. The carbon is supplied at a rate which maintains the temperature at about 98° F. The amount of CO_2 which is thus produced in 24 hours averages about 16¼ cubic feet for each adult person. Children produce a little less, and sick people often considerably more. The rate of production varies from hour to hour, being commensurate with the muscular activity of the individual.

The effect of breathing air containing an unusual amount of carbonic acid is to check the combustion going on in the lungs, mainly by crowding out the oxygen to a harmful degree. The elimination of carbon from the body then proceeds too slowly, and the result is headache, congestion, and other disorders. If the vital processes are thus checked to a considerable degree, death from suffocation is likely to ensue. If the gas is not contaminated with anything else, air containing 1½ per cent. of it may be breathed for an hour or more without harm, but in most cases it is accompanied by other poisonous compounds, which make one-tenth of that proportion hardly endurable.

ORGANIC IMPURITIES.

1915. The interior surfaces of the lungs and the whole exterior surface of the body exhale moisture continually, although at varying rates. Certain other substances, more or less volatile, are exhaled at the same time. These have a rank odor, especially when abundant, and they decompose very readily, giving rise to odors still more offensive. This class of emanations appear to have a positively toxic or poisonous effect upon those who inhale them. The exact chemical composition of these substances is difficult to determine, but long-continued and careful experiments have made it certain that they cause great discomfort and a feeling of oppression, when present in the air in moderate quantities, and that when concentrated they are dangerous.

The quantity of organic substances thus exhaled appears to bear a definite proportion to the amount of carbonic acid produced by respiration in the same time. The ratio is found to be so nearly constant that the percentage of the latter may be safely taken as an index of the quantity of the former existing in the air from the same cause.

1916. There is another large class of organic emanations which pollute the air of dwellings and assembly rooms. These proceed from the *bodies* of persons who are troubled with indigestion and various gastric and intestinal disorders. The fermentation and decomposition of the food going on in such cases give rise to considerable quantities of malodorous substances, some of which are exhaled through the skin, and others through the lungs. The breath is not only fœtid, but is liable to be charged with putrefactive germs.

In numerous cases, the breath is also made foul by the odors emitted from decaying teeth, and occasionally a case of nasal catarrh adds its disgusting effluvium to the stream of pollution which is poured forth into the air of the room at each respiration. Persons who use tobacco, whiskey, or beer, exhale the characteristic odors of these substances both through the skin and also the breath, and thus do more to pollute the air around them than they have any conception of. Many persons, otherwise well dressed, permit their clothing to become so saturated with the products of perspiration that they constantly give off rank odors, quite imperceptible to themselves, but very offensive to others.

The peculiar offensiveness of organic impurities in general fully justifies the repugnance that we feel to taking into our own lungs air which has been breathed by others, or mingled even to a small extent with the exhalations of their bodies.

DUST AND GERMS.

1917. The **dust** found in the air of dwellings, etc., is composed mainly of small fibers derived from the wear and tear of cloth and wood, and minute fragments of various kinds of stone. In thickly populated districts it is likely to contain also soot and the dried remains of decaying vegetable matter. Such dust is, as a rule, comparatively harmless, merely irritating the nostrils and lungs, but doing no positive injury unless it is present in large quantities.

But the dust from wagon roads and paved streets is much filthier in character. A considerable percentage of it consists of finely pulverized horse dung, and in the vicinity of streets paved with stone or asphaltum the greater part of the dust is found to consist of this unsavory material. Wooden pavements are still worse, because they absorb and store up the liquid excreta dropped upon them, giving it off again as dust when dried, and as a most loathsome vapor when wetted by summer showers. Of course such dust as this must be excluded from the lungs at any cost.

1918. There is another ingredient occasionally found in dust which deserves close attention, that is, the germs of putrefaction and contagious diseases. These are microscopic plants which attach themselves to the dust particles and are borne around by them. They are called by the general name of **bacteria.** They are very diverse in appearance, and also in the effects produced by their lodgment and growth. They may be divided into two great classes: those which flourish only upon dead matter, animal or vegetable, and those which thrive only upon living animals or plants, and exist at their expense.

The former class are called *saprophytes*—that is, destroyers of dead things. They break up putrescible matter and reduce it to carbonic acid, ammonia, and other simple compounds, suitable for the immediate use of ordinary growing plants. The existence of the higher forms of life in this world is believed to depend upon the activity of these saprophytes, as without them the plants could not get suitable materials for food, and all animals would, consequently, die for want of vegetable nourishment.

The other class of bacteria are true *parasites*. These are the dangerous ones. When one of them alights upon a living creature, upon a part which is both moist and warm, it begins at once to increase and multiply, some kinds slowly, and others with great rapidity. They not only rob the system by absorbing some of the fluids which should nourish the body, but they also produce virulent poisons which derange the system in various ways. Each variety of contagious disease seems to have its own specific form of bacteria, and the disease is communicated from one person to another merely by transferring one of the germs. They are carried about in many ways, not only upon particles of dust, but also upon clothing, books, and everything that may come in contact with the sick person; even pet animals, such as dogs and cats, frequently become the means of disseminating them.

Bacteria are never given off into the air from moist surfaces or liquids, unless the latter are splashed or sprayed. They do not ordinarily pass through the air, except as dry dust. Certain kinds grow in enormous numbers in the slime which covers the inside surfaces of house drains and small sewers, but there is comparatively little danger of their being carried into the house by back-drafts of air, so long as the slime is kept wet.

But if a house is closed for any considerable time, and the traps are allowed to become empty, this slime will dry up, and great numbers of bacteria will become detached in the form of dust. It is almost certain that there will be a back-draft of air from the sewer into the house in such cases, and that great numbers of the dried germs will then be carried up into the rooms. This is probably the cause of the frequent cases of severe sickness which follow the occupation, in the autumn, of houses which have stood empty during the summer.

SEWER GAS.

1919. A great many examinations have been made of the air found in sewers and drains, and it is now known positively that there is no such thing as a distinct and peculiar gas which might be called "sewer gas." This term should be understood to mean merely the gaseous contents of sewers. These consist of ordinary air mingled, in varying proportions, with the gases arising from the fermentation and decomposition of sewage.

The effect of these gases upon persons breathing them in large quantities is to induce asphyxiation and death; in less concentrated form, they cause nausea, diarrhœa, and general prostration. If a small amount is allowed to leak into a house continuously, the inmates will gradually become debilitated, their power of resisting evil influences becoming less and less, until they fall easy victims to disease.

The danger from sewer gas does not arise solely from the specific disease germs which it may carry, but principally from the peculiar and poisonous character of the gases which it contains. Hence the necessity of thoroughly ventilating all sewers and drains, and of preventing the entrance of sewer gas into the building.

GROUND AIR.

1920. Ordinary soil, which is capable of supporting grass or producing a crop of vegetables, is in reality an extensive manufactory of gas. It is here that the myriads of saprophytes, already described, perform their work of decomposing all animal and vegetable remains into elementary substances suitable for the nutriment of living plants. The result of their operation is to produce large quantities of carbonic acid, together with various ammonia compounds, and, occasionally, sulphureted hydrogen. Free ammonia, however, occurs only in very small proportions.

Carbonic acid is also produced by the chemical interactions taking place between the mineral substances contained in the soil, the amount varying with the nature of the materials and the degree of moisture.

The production of gas is most copious in soil of moderate moisture; very dry earth produces but little. When the soil is constantly saturated with water, the processes are different, and the quantity of gas evolved is usually smaller.

1921. The atmosphere penetrates the ground to a considerable depth, but its composition undergoes a great change as the depth increases. The extent of the change varies, of course, with the local conditions. At a depth of only a few inches in good ordinary soil, the air permeating it is found to contain from about 7 to 10 per cent. of oxygen, instead of the 21 per cent. present in normal air. The proportion of carbonic acid existing at the same time is, on an average, about 7 per cent. In very dry, barren soil, too poor to support vegetation, the proportion has been found as low as $\frac{1}{6}$ of one per cent., while in very rich meadow land, as high as 14 per cent. has been measured.

1922. The ground appears to be the source of the carbonic acid which pervades the atmosphere. The amount produced by the respiration of men and animals is utterly insignificant in comparison with that which constantly exudes from the soil.

Air taken from a height of 2 inches above the surface of the ground shows a larger percentage of the gases known to be generated in the soil than at a height of 5 or 6 feet, where the difference between air taken at the latter level and at a height of 40 or 50 feet is barely perceptible. The normal atmosphere contains about $\frac{1}{25}$ of one per cent. of carbonic acid, or about 4 parts in ten thousand.

It will be readily perceived, therefore, that the air which permeates the ground, or lies in contact with it, is quite unfit for breathing, and when it is remembered that the soil around dwellings is very liable to be poisoned by the leakage from gas mains, house drains, privy vaults, etc., it becomes very clear that ground air should be carefully excluded from the ventilating or heating apparatus.

CELLARS.

1923. Any excavation in the earth, such as a cellar, trench, or well, acts as a vent for the gases contained in the adjacent soil. They ooze through the sides and bottom, and gradually fill up the well, etc., precisely as water will fill a hole that is made in wet ground.

The extent to which such gases will accumulate in such places depends upon the facilities that are given them to escape and diffuse themselves into the atmosphere. In the case of a deep well, the opening into the free air is small, and gas is apt to accumulate in sufficient proportions to quickly suffocate any person descending into it; whereas, in a wide open pit of equal depth, the gas would pass into the atmosphere so freely that only an insignificant difference could be found in the air at the top and bottom.

Ordinary cellars act as collecting basins for these earth gases; and, unless adequate ventilation is provided, they will pass up through the floor and diffuse into the rooms above.

The inflow of gas can not be stopped by facing the walls or bottom with Portland cement, because gases will pass through ordinary brick, mortar, and cement, about as readily as water will percolate through a stratum of fine sand. The cement will serve to retard the flow somewhat; but, in order to stop it, substances like asphaltum or paraffin must be used.

1924. Another source of pollution in the air of cellars is found in the practice of using them to store supplies of fruit, vegetables, and coal. Potatoes and cabbages give off a considerable quantity of gas and rank odors, which are debilitating to persons who inhale them to any extent. Apples also impair the quality of the air around them, although their odor may be quite agreeable. Coal always emits gas when exposed to air, although while it is perfectly dry the amount is unimportant. But when the coal is put in the bin dripping wet, it oxidizes so rapidly that the amount of gas given off is highly deleterious. The custom of wetting the coal supplied to dwellings, etc., merely to keep down the dust while being handled, is a pernicious one and should be discouraged.

MOISTURE IN THE AIR.

1925. The presence of moisture in the atmosphere affects it in three ways: *first*, by diminishing its weight per cubic foot, thus making it more buoyant; *second*, by increasing its capacity for heat, making it more effective for either heating or cooling purposes; and *third*, by reducing the amount of oxygen contained in a cubic foot, thus impairing its value for purposes of respiration. Table 78 shows the extent of the difference between pure, dry air and air which is *saturated* with moisture; that is, containing all that it can hold at the given temperatures.

1926. The amount of moisture contained in the atmosphere has a considerable influence upon the health and comfort of persons who live in it; this point, then, is one of great importance in dealing with questions of ventilation.

TABLE 78.

EFFECT OF MOISTURE UPON AIR.

Temperature in Degrees Fahrenheit.	Weight of One Cubic Foot of Dry Air, in Pounds.	Weight of Air Displaced by Vapor, in Pounds.	Difference in Weight of One Cubic Foot of Dry and of Saturated Air, in Pounds.
10	.08451	.0002	.00007
20	.08275	.0003	.00010
30	.08105	.0005	.00017
40	.07944	.0007	.00026
50	.07788	.0010	.00037
60	.07638	.0014	.00052
70	.07494	.0019	.00078
80	.07355	.0027	.00103
90	.07222	.0036	.00128
100	.07093	.0048	.00180
110	.06968	.0063	.00235
120	.06848	.0083	.00315

Ordinarily, the sense of feeling can not be trusted in forming an estimate either of the real temperature or of the humidity of the air surrounding us. Our sensations of warmth and coolness, in air of moderate temperature, depend very largely upon the amount of evaporation going on from our bodies. When the atmosphere is dry, water is evaporated freely, both from the lungs and skin, and we feel cool and comfortable; but if the air is quite humid, the rate of evaporation is much slower, the heat generated within the body tends to accumulate, and we soon become oppressively warm. We drip with perspiration, because the air is already so full of moisture that it will not take up the water as fast as it is exuded from the skin; consequently it accumulates in the form of sweat.

Thus, air at 90°, if very nearly dry, will feel fresh and invigorating; but if the humidity be increased to 50 per cent., it will seem hot and very sultry, and if it approaches saturation, the air will become very oppressive and exhausting. As the temperature remains the same in each case, it is clear that the difference in the effects is due solely to the change in humidity.

A climate having a temperature of 100° or more for months at a time can be endured without any special discomfort so long as the humidity is low. But if the moisture increases to a degree approaching saturation, even people of strong physique will rapidly languish under its influence.

Dry air at 40° is very fresh and agreeable, if proper clothing is worn; but if it is nearly saturated with moisture it will feel very chilly, and the cold will be *penetrating*.

1927. The comfort of an audience gathered in a church or hall depends largely upon the humidity prevailing in the room. The temperature may fall to 60° without much complaint, so long as the air is kept dry; but if the humidity is allowed to rise, the complaints of cold will be both numerous and emphatic. On the other hand the temperature may rise to 75° without exciting remark, the air, as long as the humidity is not above 20 per cent., appearing delightfully fresh and pure; at 35 or 40 per cent., the audience will feel about as warm as they care to be; while if the humidity rises to 60 or 70 per cent., they will fairly swelter with heat.

Thus the variation of temperature from 60° to 75° will attract very little attention if the air remains dry; but if the humidity is allowed to rise considerably, this change in temperature will make all the difference between the conditions of *chilly* and *unbearably warm*.

This explains the failure of the attempts that have often been made to cool the air of large audience rooms, in summer time, by passing it over wet screens or through a spray of water. Although the air was slightly reduced in temperature, yet the humidity was increased at the same time to such an extent that its effects not only neutralized the fall in temperature but made the air less comfortable than before.

A high degree of humidity is not desirable in any case for air that is to be breathed. European engineers recommend for dwellings, etc., that the humidity be made 60 to 70 per cent. But the climate of the United States is so different that a lower rate must be employed. Extensive observation shows that in this country the humidity should be from 30 to 40 per cent. of saturation.

1928. Dry air is not essentially unhealthy. While it is true that it will dry the eyes, lips, and throat to an uncomfortable degree, yet these discomforts are merely superficial and do not lead to serious results unless continued for a long time, or the subject be otherwise debilitated. Most of the evil effects produced by air that has been passed through furnaces or other heating apparatus are due to its contamination, or its excessive heat—very little can be justly charged to its dryness. As a general rule, the air in an apartment may be considered sufficiently humid so long as no irritation of the eyes or throat becomes noticeable.

1929. Loss of Oxygen.—The proportion of oxygen in the atmosphere is reduced somewhat by the presence of moisture in it. Usually the loss is so small that it may be neglected, but under some circumstances it becomes large enough to require consideration. By referring to Table 78, it will be seen that a cubic foot of perfectly dry air at 70° weighs .0750 pound nearly, while the amount of pure air (that is, dry oxygen and nitrogen) to be found in the same volume of saturated air is only .0731 pound, the difference, .0019 pound, having been displaced by the vapor or steam. Thus the air loses 19 parts of its oxygen, etc., out of 750, by becoming saturated; consequently, its value of respiration is reduced $\frac{19}{750}$, or about $2\frac{1}{2}$ per cent. In a similar manner, air at 100° loses about $6\frac{1}{2}$ per cent. of its value for breathing purposes.

1930. This deterioration of the atmosphere by the presence of moisture in excessive amounts is often very plainly felt during hot summer weather, just before a storm. At such times the humidity approaches saturation, and the deficiency of oxygen is so great that people pant for breath. The evaporation from the surfaces of the body is greatly diminished, allowing the bodily heat to accumulate, and this adds to the feeling of depression and distress. The same thing is liable to occur in laundries, cooking rooms, dye-houses, and other places where the temperature and humidity are both high.

1931. Buoyancy.—Atmospheric steam or water vapor is much lighter than air at the same temperature, consequently any mixture of vapor and air is lighter than pure dry air. The belief that damp air is necessarily heavy, and therefore inclined to sink to the bottom, is wholly erroneous. In those cases where it is seen to gravitate downwards, it will be found that the movement is due to the fact that its temperature is considerably lower than that of the surrounding atmosphere. A difference in the humidity, at various levels, of a body of air having a uniform temperature throughout, will cause circulation, precisely as a difference in temperature would do.

The circulation which takes place in a ventilating stack in summer time is largely aided by .the humidity of the air at its base. The interior of a house is apt to be more humid, especially in the lower stories, than the atmosphere at the top of the stack.

The steam jets which are sometimes used at the base of a stack to increase the draft, owe part of their efficiency to the humidity which they impart to the rising column of air, making it lighter than it would otherwise be.

The air in kitchens and laundries is not only warm, but also quite humid; consequently, it is exceedingly buoyant. This explains the strong tendency evinced by kitchen odors, etc., to ascend and pervade the upper parts of the house.

QUANTITY OF AIR REQUIRED.

1932. In order to answer this question properly, it is necessary to know the effects produced by breathing foul air, not merely for a few hours, but for long periods of time. A large number of competent investigators have observed its effects upon soldiers occupying poorly ventilated barracks, and upon operatives working in close workrooms, etc., the observations extending over a period of many years. A comparison of the results thus obtained proves the slow but certain production of throat and lung troubles, and the constant loss of energy and vitality which shortens life to a serious extent, and makes existence a burden instead of a pleasure.

1933. There is only one way by which the fitness of air for respiration can be determined with any certainty, and that is by chemical examination. The sense of smell can not be depended on for this purpose, because it is so easily blunted. After remaining in a room full of bad air for 10 or 15 minutes, a person will usually be unable to perceive any unpleasant odor about it. It is only upon passing from the fresh outdoor air into a tainted atmosphere that the sense of smell can be relied upon to discover the bad quality of the air, but even then no accurate estimate can be made of the real degree of pollution.

When the carbonic acid gas due to respiration and exhalation does not amount to more than 2 parts in 10,000, the air still smells fresh and wholesome. When a definite animal or musty odor begins to be perceptible, the air is said to be *rather close*, and the exhaled carbonic acid gas is found to amount to 4 or 5 parts. When the proportion increases to 7 or 8 parts, the air is called *close* or *very close*, and when it reaches 12 parts in 10,000 the air is pronounced *very bad*. Above this point, the sense of smell fails to perceive any marked difference.

1934. Proper ventilation requires that the exhaled carbonic acid should not be allowed at any time to rise above 2 parts in 10,000. The amount of air that will be required per minute to maintain this degree of freshness may be readily computed.

Each adult person in good health breathes out about .7 of a cubic foot of carbonic acid per hour, and in the same time exhales from the lungs and skin about .091 pound of water, which at 70° becomes about 80 cubic feet of steam or vapor.

He also imparts about 400 heat units per hour to the air of the room, by conduction and radiation from his body. The air supplied for ventilation must, therefore, serve three purposes: to dilute the carbonic acid to a proper degree; to absorb the vapors exhaled, without permitting any noticeable increase in the humidity; and to absorb the heat as rapidly as emitted, without perceptible rise of temperature.

In order to dilute .7 of a cubic foot of carbonic acid to the proportion of 2 parts in 10,000, it is necessary to mix it with $\frac{10,000 \times .7}{2} = 3,500$ cubic feet of air. Therefore, the air supply should be 3,500 cubic feet per hour for each adult person, or nearly 1 cubic foot per second. Taking into consideration the smaller amount of carbonic acid produced by children, the supply for schoolrooms and similar places may be reckoned at 3,000 cubic feet per person, per hour.

1935. This amount of air will also be sufficient to properly absorb the vapor and heat. The addition of 80 cubic feet of vapor to 3,000 cubic feet of air at 70° will increase the humidity only about 2.6 per cent, which is not enough to be objectionable unless the moisture of the air is much too high on entering. The heat, however, has a more noticeable effect. As each unit of heat will raise the temperature of about 55 cubic feet of air 1°, it follows that 400 heat units will heat 3,000 cubic feet about 7.3°. No such rise of temperature can ever be observed, however, except under extraordinary conditions, because a much greater amount of heat is lost from the room in the same time by conduction through the walls, windows, etc., and consequently none accumulates

An allowance of 3,000 cubic feet per hour, or 50 feet per minute, is the smallest that should ever be made; and it is advisable to increase the supply whenever it can be done without unreasonable expense.

This allowance is really very meager, although the figures might give the contrary impression.

1936. Thus far, in reckoning the quantity of air required, no account has been taken of any other source of contamination than the respiration and exhalations of persons occupying the apartments. But lamps and gas burners produce large amounts of carbonic acid, and occasionally other gases of a more harmful nature. Ordinarily these products of combustion do not need so much dilution as the products of respiration, and for purposes of computation the allowable proportion may be assumed as 10 parts in 10,000. Electric incandescent lamps do not vitiate the air, because there is no combustion present.

It must not be forgotten that when gas is burned, a considerable amount of moisture is added to the air, all of the hydrogen being converted into water. When a large number of gas lights are employed, the humidity is likely to be increased to a degree which will require attention to prevent it becoming disagreeable.

1937. The volume of the air supply required varies with the season and the condition of the outer atmosphere. In clear, cold weather, 3,000 feet per hour per head is sufficient for good ventilation; but on a mild spring day, with a damp, muggy atmosphere, it is difficult to get air enough without getting too much heat at the same time. *The air is not dried* in the least by passing through heaters, and is so moist and warm that it fails to remove the animal heat as fast as necessary. Where people are assembled in considerable numbers, as in schools, etc., it is likely to produce feelings of great lassitude, and even fainting spells. On such occasions as these, it is highly desirable to have some means for reducing the humidity of the air.

CUBIC SPACE.

1938. It is impracticable to make any proper calculations for ventilation or heating upon a basis of the **cubic space** contained in an apartment. The amount of air required depends solely upon the number of persons occupying the room, and upon the nature and extent of the contaminating influences. The *size* of the room does not enter into the calculation. Thus, 60 people require precisely the same amount of air, whether they are packed in a rail road car or are scattered over a large hall.

1939. The requirements of heating are equally independent of cubic space. The amount of heat to be supplied depends wholly upon the amount lost through cooling surfaces and by ventilation. It varies with every change in the temperature of the outer atmosphere, and must be modified to suit occasions of excessive humidity.

Thus, it is seen that a knowledge of the cubic space to be ventilated or warmed affords no data for computing the supply of either air or heat. All rules, therefore, which are based upon the volume of the room are empirical, and are mere aids to guesswork. It is the practice of many heating engineers to assume that the air should be changed a certain (arbitrary) number of times per hour, instead of computing the amount required by the persons occupying the room. This proceeding, however, is not a rational one, and the results arrived at are little more than mere guesswork.

1940. Cubic space is not an important factor in ventilation, but there is a certain **minimum space** required for each person, which must never be disregarded. The carbonic acid and other exhalations from the body diffuse themselves through the air with comparative slowness, and in order to secure their dispersion into the atmosphere with proper rapidity, it is necessary that every person should have a certain amount of "breathing room."

The minimum space that may be permitted, in cubic feet per person, is as follows:

In a lodging or tenement house...	300 cubic feet.
In a schoolroom..................	250 cubic feet.
Barracks.........................	600 cubic feet.
Ordinary hospital ward...........	1,000 cubic feet.
Fever or surgical ward...........	1,400 cubic feet.

1941. Floor space must be considered as much as mere cubic space. Thus, in a schoolroom, there must be an aggregate of 25 square feet of floor surface for each pupil;

and in hospitals each bed must have 100 square feet of floor space.

In stables, each horse or cow should have 100 square feet of floor space. A horse should have 1,600 cubic feet of air space, and a cow not less than 1,200. As cows are usually kept to furnish milk for food, it is important that they should be kept in a healthy condition, and that the air around them should be clean. The practice of furnishing their quarters with plenty of good air has been found highly beneficial.

TESTING AIR.

1942. To make an analysis of air, with a view to discovering the proportions of carbonic acid and other impurities in it, is properly the work of an experienced chemist. An amateur can not reasonably expect to secure very accurate results, because accuracy depends, in great part, upon the skill and care taken in handling the apparatus, and in preparing the materials. With a little practice, however, and a few lessons from some practical chemist accustomed to dealing with gases, sufficient accuracy for ordinary practical purposes may be acquired.

Although CO_2 is really not the most dangerous impurity, yet the amount of it present in excess of that contained in the outer atmosphere is known to very accurately denote the degree of vitiation, and the vitiation is usually designated by the number of parts of CO_2 in each 10,000 parts of air.

The proportions of CO_2 likely to be found in the air of inhabited buildings will range from 2 to 20 parts in 10,000; and all analyses must be accurate to at least 1 part in 10,000, in order to be of practical value.

Numerous instruments have been devised and put upon the market to indicate the presence of CO_2 in a sample of air, by an exposure of a few minutes; and others have been constructed to indicate the proportion continuously, just as a thermometer indicates temperature. A careful comparison of these instruments with precise chemical methods of analysis shows that they are grossly inaccurate, and are not to be relied upon.

The proportions of the other impurities, such as carbon monoxide, ammonia, or organic matter, can be determined only by methods which require the skill of an experienced chemist.

TAKING SAMPLES OF AIR.

1943. In order to secure a sample of air, a gas bag is generally employed. The bag is rolled up tight, or otherwise compressed to ensure its emptiness, before it is taken into the room where the sample is to be taken. In taking the sample at the place desired, great care must be exercised to avoid taking in an undue share of the breath exhaled by the operator. Persons must not be allowed to stand around the apparatus to see what is going on; on the contrary, they should all be required to remain in their places, or at least to keep a respectable distance away. The analyses are liable to yield some amazing results if this precaution is neglected.

If a pump is used to fill the bag, the pumping should be stopped before any pressure is put upon it. If the air is put under pressure, the CO_2 is liable to leak out by soaking through the fabric; and the same thing is liable to occur if the bag is allowed to lie a long time before the contents are examined. No bag should ever be used for this purpose which has been used for holding any other kind of gas.

The best way to conduct analyses of air in buildings, although not always the most convenient, is to set up the analyzing apparatus in the room to be examined, and to take the air in through clean tubing when necessary.

METHOD OF MEASURING CO_2.

1944. The method here given is the only one generally known which is sufficiently convenient and accurate to be recommended in connection with ventilating operations. The process is based on the fact that a solution of caustic potash will absorb carbonic acid without affecting the other constituents of the air. For use in this connection, the solution must be *saturated*, and the chemicals must be pure.

1945. The apparatus is shown in Fig. 775, and can be readily obtained from any dealer in chemical supplies. The parts of the apparatus are secured in place within openings made in the vertical board *a*, and stability is afforded by the square base *b*. It consists of a vertical glass tube *d*, which is graduated throughout the greater part of its length; and a **U**-shaped bottle or burette *e*, which is connected to *d* by a stop-cock *f*. A small pressure gauge *g h*, having a drop of liquid moving along a graduated scale at *i*, is connected to *d* by means of the stop-cock *k*. The other end of the gauge tube is connected to an air chamber *l*. The flask *m* is connected to the base of the tube *d* by the rubber tube *c*, and is designed to act as a pump. Both *m* and *d* are partially filled with mercury, and the contents of the latter are expelled by raising the flask until the mercury rises to the top of the chamber. The air to be tested is then drawn in through the cock *n* by lowering the flask, the mercury in *d* being lowered to the zero of the scale. The cocks *f*, *n*, *k*, *g*, *h* being open, the position of the index *i* is noted, and all the cocks are then closed except *f*. The flask *m* is then raised, until all the air is drawn from *d* over into the burette *e*, which is filled half full with a saturated solution of pure caustic potash, through the stopper *w*. This substance quickly absorbs the CO_2, and thus reduces the volume of the air under examination. The air is shifted back and forth from *d* to *e* several times, being finally drawn back into *d*, and the stop-cock *k* opened to the pressure gauge. The flask is next raised or lowered until the index *i* stands at the point

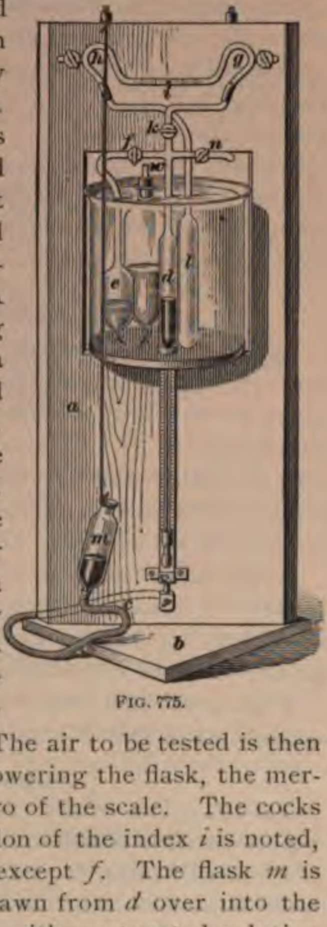

FIG. 775.

water in the lower pans will become quite cold, and but little evaporation will take place. Each pan should have a separate supply pipe *a*, and the feed for each one should be regulated by an independent cock, as shown at *b*.

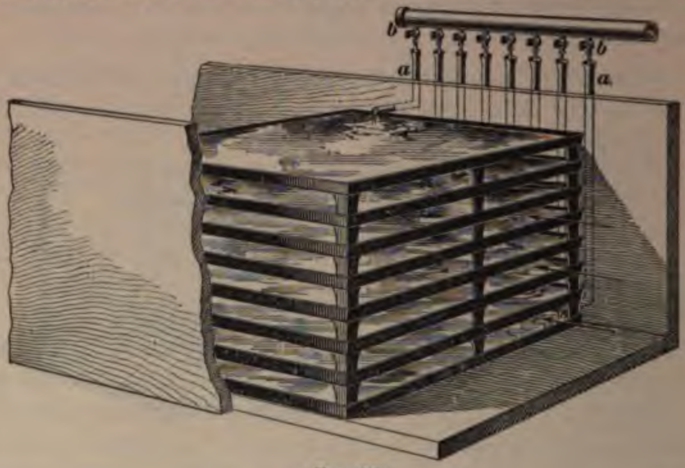

FIG. 777.

1950. A great many devices have been invented for projecting water into the air-current in the form of finely divided spray. A favorite device is a fan having water jets attached to the blades, water being supplied through the fan shaft, which is hollow. The machines serve to load the air with water, but the water is held only in mechanical suspension, instead of being evaporated and transformed into true steam. They are useful for dampening materials in process of manufacture, such as cloth, paper, tobacco, etc.; but they are wrong in principle when used for humidifying the air for ventilating purposes.

It is at this point that the old delusion that air actually absorbs moisture becomes very misleading. Air can not be wetted, although it can be made to carry water to some distance by entrainment. It should be clearly understood that the problem of humidification is to make steam, and that this can be done only by evaporation. The quantity of steam to be made must, when added to that already existing in the atmosphere, be fully equal to the volume of the air-current, and its pressure or density must be that corresponding to a boiling point of about 40° F., that is, the desired dew point of the air when delivered.

The heat required for evaporation, in the cases shown in Figs. 776 and 777, is absorbed from the air-current.

1951. A very convenient method of humidifying a current of air is to inject steam into it. The jet should blow at right angles to the direction of the current, so that the steam will diffuse readily throughout the whole mass of air. If the area of the airway is large, several small jets, distributed around the periphery, should be employed instead of a single large one. The orifices usually required are very small, but they should never be made less than $\frac{1}{32}$ inch in diameter, because such fine holes are very liable to become clogged and cease to operate.

The weight of steam that will be discharged into the atmosphere, per hour, through jets of small diameter, the pressure being not lower than about 20 pounds per square inch absolute, is found to be as follows:

Orifice $\frac{1}{32}$ inch diameter = .03944 pound,
Orifice $\frac{1}{16}$ inch diameter = .15770 pound.

At lower pressures, the rate of discharge becomes slower and can not be conveniently computed.

DRYING AND COOLING AIR.

1952. The process of drying air is just the reverse of that for drying cloth and other wet materials.

In the ordinary process of drying, the materials are heated, in order to convert the moisture into steam and drive it off into the atmosphere; but in dealing with humid air, the only way by which the moisture can be reduced is by condensing a part of it.

Air can not possibly be dried by heating it; on the contrary, if hot air encounters any water, it will impart heat to it and cause more evaporation, thus actually increasing the amount of vapor per cubic foot of space. The only practicable method, therefore, of drying air, that is, of condensing the atmospheric steam, is to lower its temperature.

It will be seen from the foregoing that the processes of drying and cooling air naturally go together, and that drying and heating are quite incompatible and can not be performed at the same time.

1953. The method usually adopted for this purpose is to pass the air over trays containing ice, or over pipe coils containing cold brine or other refrigerating liquids. It has been attempted in many cases to perform the work with coils which were filled with water at ordinary natural temperature, but the results were not entirely satisfactory.

In order to give the air an agreeable feeling of *freshness*, its humidity must be reduced to 40 per cent. or less. This may be done by lowering the dew point to 40° F. or less. The refrigerating liquids employed must have a temperature about the same as that of ice.

Apparatus which employs natural water in the coils is useful for cooling purposes only; it is quite incapable of drying ordinary air, because the water seldom has a temperature in summer time of less than 55° or 60°, and, consequently, can not lower the dew point below 60°. The humidity of air at 70°, having its dew point at 60°, would be about 71 per cent., which is far too high to be comfortable. In this respect, such apparatus is quite inferior to that in which ice or cold refrigerating liquids are employed.

The methods and apparatus shown in Figs. 776 and 777 should never be used for cooling air, except in places where moisture is of no importance. They are wholly unfit for use in dwellings or public buildings of any kind, because evaporation will invariably take place, and thus increase the humidity to an extent which will prove very disagreeable.

FILTERING AIR.

1954. The object of filtration is to arrest dust, smoke, etc., and prevent it from passing into the building. The apparatus employed is of two classes: wet and dry.

A **wet filter** consists of a coarse netting, which is stretched across the airway and is kept constantly wet or moist. The net may be made of small rope or other rough fiber, and should have a mesh not larger than one inch. The water should be allowed to trickle down over it constantly, keeping it wet enough to make the dust adhere wherever it touches. The net gradually becomes loaded with dirt, which requires to be washed off. This may be done automatically by means of an ordinary periodical flushing tank, arranged to empty a liberal supply of water over the screen.

A **dry screen** for a large airway may be constructed as shown in Fig. 778. A set of inclined screens *a* are supported upon transverse bars *b* and *c*. These screens are made of wire wetting, having a mesh of 2 inches or more; and their purpose is to support other screens made of cheese cloth or light muslin. They are fixed in place, and do not need to be removed for cleaning.

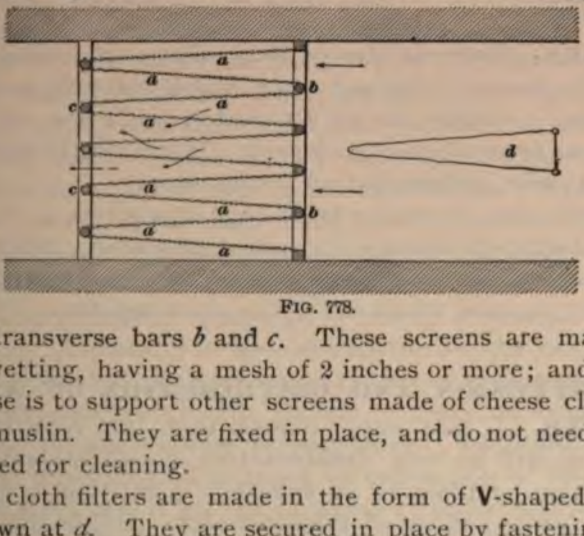

FIG. 778.

The cloth filters are made in the form of V-shaped bags, as shown at *d*. They are secured in place by fastening the front edges to the bars *b*; the air entering at the open mouth inflates them so that they lie tightly against the wire screens *a*. The total area of filtering surface thus exposed should be 8 to 10 times the sectional area of the airway.

The filter bags must be removed at intervals and emptied of dust, and they should also be thoroughly washed and dried before they are used again.

Fig. 779 shows a **filter bag** applied to the air inlet of an ordinary dwelling. The bag *a* is provided at the mouth with a stiff wire frame, by which it can be readily attached to the inlet box *b*. The end *c* is made of stiff canvas to hold the dirt. Only the upper half of the bag will be serviceable for filtering purposes, the lower half being in contact with the bottom of the flue *d*. New bags should be washed before being used, so as to remove any starch or stiffening that may be in the cloth. A handhole is placed at *e*, through which the bag may be removed from the duct.

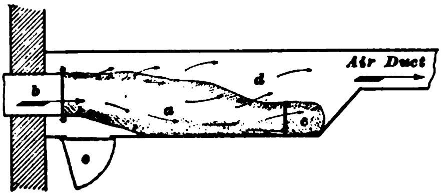

FIG 779.

1955. Both varieties of filter offer considerable resistance to the air. The wet filter, unless carefully managed, is liable to make the air too damp; while the dry filter requires to be frequently cleaned. If cleaning is neglected, it will choke up and shut off the air supply.

When dust is dealt with in large quantities, as in some manufacturing operations, special machines called **dust collectors** are employed. These are constructed in a variety of ways, which can not be described here.

DIFFUSION AND DISTRIBUTION OF AIR.

1956. It may easily happen that the ventilation of a room will be very unsatisfactory, notwithstanding that a current of fresh air of sufficient quantity is constantly passing into and out of the apartment. Unless the incoming air is introduced in a proper manner, it may pass in a nearly unbroken current from the inlet to the outlet, and practically fail to disturb and renew the main body of air in the room.

It is quite as necessary to secure thorough distribution and diffusion of the fresh air as to provide an inlet and outlet. *Good ventilation* requires that the foul air shall be well mixed and diluted with that which is pure; but whether the desired mixing will take place or not depends mainly upon the care and skill employed to ensure the conditions necessary for proper diffusion. Neglect at this point has led to many serious failures in ventilating buildings.

1957. The tendency of a gas, when released in still air, is to diffuse equally in all directions. The fact that it is heavier or lighter than an equal volume of air does not prevent or interfere with its complete and uniform diffusion. Gravitation does not affect diffusion to any appreciable extent. A mixture of light and heavy gases will always remain a perfect mixture, and will never separate into layers according to their weights, except under peculiar and artificial conditions, which need not be considered here.

Carbonic acid obeys the same law of diffusion as other gases; that is, it diffuses uniformly throughout space and does not settle down and form a heavy stratum at the bottom of a room. There is, however, a great difference in the rate at which various gases will diffuse. Hydrogen diffuses into air many times faster than carbonic acid. The vapor and organic odors exhaled from the body also require considerable time for proper dispersion.

Diffusion, strictly speaking, is merely a process of expansion. A quantity of gas liberated in a room has, when pure, an absolute pressure equal to that of the atmosphere. But it expands until it fills the entire space uniformly, its absolute pressure falling in proportion. The diffusion of sluggish gases may be hastened by convection or mechanical agitation, and it will be impeded by differences in temperature. Diffusion proceeds best when the whole body of air is at a uniform temperature.

In still, cold air the products of respiration, being warm, ascend at a rate slightly greater than the rate of diffusion: consequently, there is sometimes a little more carbonic acid, etc., to be found near the ceiling than near the floor, but, as a rule, it is uniformly distributed throughout the space. If there is a strong upward current of air from floor registers, gas lights, etc., this difference may be very great. It often happens in such cases that while the air at the breathing level is reasonably pure, at the ceiling it is fœtid and suffocating. In order to secure good ventilation, this accumulation of bad air in the upper part of the room must be prevented.

DIFFUSION OF WARM AIR.

1958. If warm, fresh air is introduced near the top of a room it will lie against the ceiling in a body, and will not diffuse to any satisfactory extent into the colder air below. To get it down to the breathing level, it must be driven down by force; there is no other way.

If it is introduced through a register in the floor, it will quickly ascend to the ceiling and will not mix freely with the cooler air through which it passes. The tendency of ascending currents of hot air is to flow in well-defined streaks, the separation becoming more marked as the difference in temperature increases. The diffusion may be greatly improved by introducing the hot air in a large number of small streams, but this is impracticable in many cases on account of the expense involved.

The smaller the difference in temperature between two bodies of air, the more readily will the one diffuse into the other; therefore, it is always advisable to introduce the fresh warm air at a temperature as little above the desired constant temperature of the room as possible. It is not practicable to warm a room satisfactorily with a current of highly heated air, because it can not be made to diffuse uniformly, and one part of the room will be much warmer than another.

1959. Adhesion of Currents to Surfaces.—Another important property of air-currents, both hot and cold, which is of great importance in the art of ventilation, is their tendency to adhere to surfaces along which they happen to be moving. For instance, if a current flows horizontally through an opening at the level of the floor, it will keep close to the floor and be plainly perceptible a long distance away; but a similar current issuing from an opening in the wall midway between the floor and ceiling would be quite imperceptible at only a few feet in front of the register.

In a similar manner, a current of cold air formed by the cooling action of a large window will, in many cases, descend and creep along the floor almost to the opposite side of the room before it diffuses, making it very uncomfortable around the feet and ankles of the occupants. In this way, annoying drafts may occur at points where they are least expected.

This matter must be carefully considered in locating warm-air registers; otherwise, diffusion of the fresh air may be defeated. And, on the other hand, it may be practicable, under some circumstances, to utilize this property of air-currents so as to secure the delivery of air to points quite remote from the register.

Many ventilating projects in which the air has been introduced through numerous openings in the floor, or in the risers of stepped floors, have yielded very disagreeable results because this matter was not duly considered.

ACOUSTIC EFFECTS OF AIR-CURRENTS.

1960. It is a matter of great importance in all public buildings, such as churches, theaters, lecture rooms, etc., that a person speaking from the stage or platform should be distinctly heard at any point on the floor or in the galleries.

The transmission of sound is affected to a considerable degree by currents in the air, and by variations in its density or temperature. If a sound projected by the speaker encounters an air-current, it will be deflected from its original course and will appear to the hearer to be somewhat weaker than it otherwise would. If a number of currents are encountered the weakening effect will be very noticeable.

The greatest obstruction, however, is caused by inequalities in the temperature of the air through which the sound passes.

Sound is always retarded by passing from a denser medium into a lighter one, and *vice versa.* When an audience room is full of streaks of warm air, either ascending or descending, the voice of the speaker will be so retarded in passing through them successively that persons in the remoter parts of the room will have great difficulty in hearing plainly.

It is well known that there is a great difference in the acoustic properties of a hall when empty, and when full of people. The presence of the audience seems to weaken and obstruct the sounds made by the speaker. Part of this effect is due to the rustling and other light noises made by the occupants, but the greater part of the obstructive effect is caused by the change in the condition of the air. Instead of its being of a nearly uniform density throughout, as was the case when the room was empty, it becomes diversified by numerous small currents of moist, warm air, one of which ascends steadily from each individual in the assembly. These, together with the hot currents rising from floor registers, gas burners, etc., make the air so uneven in density or texture that sound travels through it with difficulty.

1961. The practice of introducing the warm air through large openings in the vertical front of the stage, or through large floor registers between the audience and the speaker's platform, is for these reasons a bad one, and should be carefully avoided.

The trouble in most auditoriums having poor acoustic properties lies in the improper shape given to the room; but, in many cases, rooms which are otherwise well designed and constructed are completely spoiled for speaking purposes, by improper heating arrangements.

GENERAL ARRANGEMENTS.

UPWARD AND DOWNWARD VENTILATION.

1962. The comparative advantages of these opposing systems of ventilation may be briefly stated as follows:

1. The currents of warm air arising from human beings and containing the exhalations and products of respiration are warmer than the surrounding air, and naturally tend to

move upwards. Thus they tend to assist upward ventilation and to impede downward movement. The amount of force required to overcome the rising tendency of these currents is so small, however, that it need not be considered in cases where fans are used for forcing the air, nor, in fact, in any case, except where ventilating chimneys having comparatively weak draft are employed.

2. The hot air and gases produced by gas burners, etc., have a strong upward tendency, and in some cases may be a valuable auxiliary to upward ventilation. When the downward system is used, these lights should be enclosed, and the products of combustion carried away to avoid contaminating the fresh air. Usually these hot gases can be utilized to increase the draft, by discharging them into the foul-air flues.

3. The direction of the ventilating movement has only a very slight effect in varying the distribution of the exhalations and products of respiration throughout the room. The tendency which these have to float upwards is counteracted in the downward system by the general movement of the air, and they are swept down to the floor and into the outlet flues. In the upward system, they are merely carried in the opposite direction. The quality of the air at the breathing level depends mainly upon the proportion of fresh air supplied.

4. In rooms that are likely to be fully occupied, it is difficult to locate the fresh-air openings in or near the floor so that the incoming currents will not impinge on some part of the bodies of the occupants and produce disagreeable sensations. The difficulty is aggravated by the tendency of air-currents to adhere to the surfaces, both vertical and horizontal.

In downward ventilation, the incoming currents are likely to be dissipated before they reach the lower part of the room, and, consequently they may be comparatively few in number and larger in volume, and may have a higher velocity. The foul air may, without producing uncomfortable feelings, be taken out through floor openings at a higher velocity than could be allowed for inflowing currents.

5. The ascending air-currents employed in the upward system tend to carry up into the breathing zone the dust and other offensive matters which otherwise would lie upon the floor. As the upward flow is continuous, the dust is kept in constant circulation, and no opportunity is given it to settle. Downward currents, on the contrary, will carry it directly into the outlets and thus dispose of it.

6. In audience rooms of great height, having balconies and galleries, either system may be applied successfully, so far as the distribution of fresh air and heat is concerned, but the acoustic properties are likely to be better with the downward system, because the main body of air is more likely to be uniform in density and temperature, and free from perceptible currents.

THE EXHAUST AND PRESSURE SYSTEMS.

1963. Air may be moved and distributed with equal facility by either of these systems, provided that the difference in pressure, above or below the atmosphere, is the same, and that the apparatus is of equal capacity.

But the leakage of air which takes place through every hole and crevice in the walls, and around every loose-fitting window, etc., affects the exhaust system far more seriously than the other. It is often a difficult matter to prevent the entrance of air from foul and unclean sources; in fact, it is necessary, in order to fully prevent contamination, that every possible inlet should be known and controlled.

When air is drawn through a heating apparatus consisting of a hot-air furnace, some of the products of combustion are certain to leak through the furnace joints and poison the air supply. With the pressure system, no leakage of gas is likely to occur. On the contrary, the fresh air is likely to force its way into the interior of the furnace.

The practical difference between the two systems may be clearly perceived by considering the exhaust system as having a single outlet, but a multitude of inlets; while the pressure system has numerous outlets, but only one inlet. The purity of the air supply must be controlled at the inlet, and it is practically much easier to supervise one large inlet than a multitude of small ones. Otherwise, the real points of difference in the two systems are unimportant.

Usually the terms **exhaust** and **pressure** are applied only to those systems which are operated by fans or steam blowers, but the same difference in principle exists between those operated by heat or gravity. Thus, the **aspiration** system, which depends upon the draft of a central foul-air chimney, is essentially an exhaust system, because the pressure within the rooms is slightly lower than in the external atmosphere. The ordinary **natural draft** system, operated by a hot-air furnace or by indirect radiators, is in principle a pressure system, the internal pressure being a little above that of the atmosphere. The difference in either case is the measure of the force of the draft.

THE ASPIRATION SYSTEM.

1964. In this system, all of the foul-air flues are brought together and connected into a single large chimney or shaft, so that there is practically only one outlet. There are three methods in vogue of arranging the flues and the movement of the air:

1. To carry a separate flue from each room to the attic, where they converge into a few large ones and finally enter the base of the aspirating shaft. The shaft, in this case, starts from the attic and does not extend down through the lower stories.

2. To carry each foul-air flue horizontally and connect it directly into the aspirating shaft, which in this case must extend through the entire building.

3. To carry the flues downwards into the basement, and connect them to the stack at the lowest practicable level.

1965. In the first and third methods, the number of flues increases with the height of the building, being most numerous in the upper story in the former case, and in the first story in the latter case. In high buildings, the lower walls must have considerable thickness to secure the necessary strength, and the presence of any considerable number of flues makes it necessary to increase the thickness. In many cases, this increase is very inconvenient and objectionable. On the contrary, the walls in the upper stories are naturally much thinner, and the thickening necessary to include the flues is unobjectionable.

When the flues are carried horizontally, as in the second method, it is often found difficult to extend them across corridors and hallways without making an unsightly construction, the floor girders being in the way.

An aspirating chimney which extends to the basement is necessarily much more expensive than one which starts from the attic. The latter may be built of wood and lined with tin, or may be made of light plate iron; but the former will usually be built of brick. The space required for a brick chimney of this kind is considerable, not only on account of the thickness of the walls required in the lower stories, but also because the sectional area necessary to carry the foul air and allow for frictional resistance is so large.

In practice, the velocity of the air will seldom exceed 6 feet per second, and the area of the shaft should be calculated upon that basis. In cases where an exhaust fan or steam jet exhauster can be used, the estimate of velocity may be increased to 8 or possibly 10 feet per second.

1966. The principal advantage possessed by the third method over the first is the facility which it affords for using heaters at the base of the stack to aid the draft. A part of the increase in draft pressure gained in that way is spent in overcoming the resistance offered by the foul air while descending the flues to the basement; consequently, the net gain is not very great.

When an aspirating fan or a steam jet exhauster is employed to increase the draft, instead of a heater of some kind, the advantage of cost and convenience is largely in favor of the first or upward method.

AUXILIARY APPARATUS.

1967. During the cold season, the difference in temperature between the foul air and the outer atmosphere is usually sufficient to create a satisfactory draft in the aspirating chimney. In addition, the hot gases from the heating apparatus may be turned into the stack to increase the temperature and aid the draft. But during mild weather, the temperature difference diminishes, and in summer time it dwindles to almost nothing, on some occasions being actually reversed. The chimney thus becomes impotent and inoperative as the weather becomes warmer, and other apparatus must then be employed to aid in maintaining the ventilation.

The auxiliary apparatus employed for this purpose consists of steam coils, stoves, grates, and gas burners, located at the base of the stack.

1968. **Steam coils,** in order to be effective, should be placed crosswise of the foul-air current, and the pipes should be spaced wide apart, so as to impede the current as little as possible. The requisite number can be used by placing them in several tiers; 1½-inch pipes should be spaced not less than 4 inches apart between centers.

If the coils are located in the stack, they should be placed horizontally, about as shown in Fig. 780, care being taken to ensure perfect drainage. It is poor practice to arrange steam coils vertically and around the sides of the stack, because only a small part of the air will come into actual contact with them and be properly heated.

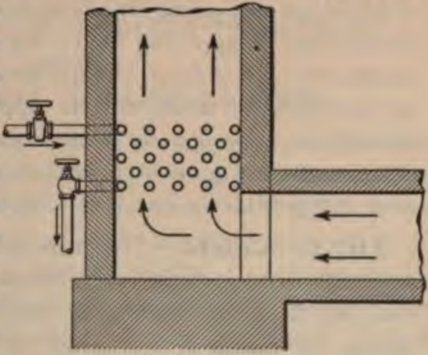

FIG. 780.

The coils should be placed as low down in the stack as practicable, in order to secure the greatest available height for the column of warm air, and every foul-air inlet should enter below, but never above them.

1969. Common stoves and basket grates are very inefficient apparatus for the above purpose. They are generally set up in the bottom of the stack, and it is assumed that, because they are in a current of air, they will have plenty of draft. This is a mistake, however, the pressure of the air being practically the same both above and below the fire, and the only force which serves to drive air through the fuel is the momentum of the current. The combustion is very imperfect, and the amount of heat developed is much less than in a similar stove having a good draft. The area of heating surface is so limited that only a small portion of the air-current can come into contact with it. The hot gases of combustion ascend a long distance in the chimney before they give up their surplus heat to the air surrounding them. Thus the actual application of heat is so tardy that the average temperature throughout the stack is likely to be considerably less than if an equal amount of heat had been communicated by a coil at the bottom. If a stove or grate must be used at the base of an aspirating stack, it should be provided with a smoke pipe extending a sufficient distance upwards within the stack to secure a good draft.

1970. The use of ordinary **gas burners** to aid the draft in an aspirating flue is an exceedingly crude and wasteful method of applying heat. In order to develop the maximum amount of heat, the gas should be burned in a Bunsen burner of some kind, and to apply the heat effectively, it should be absorbed by some metallic body having a large area of emitting surface, and thence be imparted to the air at a comparatively low temperature.

1971. Cowls.—The principal use of a **cowl** is to prevent the wind from blowing down the chimney, and to keep out the rain and snow. A properly constructed cowl will utilize the force of the wind to increase the draft, but it operates in that way *only while the wind blows.* During calm weather, it is always more or less of an obstruction.

All claims that a cowl of any kind will aid the draft *in still air* are fallacious.

Ventilation is most needed when the atmosphere is still and humid, and at such times a cowl is not only useless but is positively detrimental. Therefore they should be used only in places where they are needed to prevent **back-drafts** or **blow-downs.**

1972. Dampers.—When it is desired to diminish or control the discharge of air from an aspirating chimney by means of a valve or damper of any kind, the damper should be located at or near the top of the stack, and not at its base. When the air is partly shut off at the bottom, the current passing up the stack is so weak that it is liable to be neutralized or reversed by cold contrary currents flowing down the interior.

The method of checking the draft by admitting cold air into the flue from outdoors is not to be recommended. It cools the chimney so that the draft becomes very precarious and uncertain.

1973. Counterdrafts.—If the building is a high one, and has a central hall with stairways running to the top story, there is likely to be a strong draft up the stairs, which will antagonize the draft of the aspirating chimney. The only way to obviate this trouble is to build partitions across the hall, and thus cut off the upward circulation.

THE NATURAL DRAFT SYSTEM.

1974. In this system, special arrangements are seldom employed for exhausting the foul air from the rooms. The fresh air enters at the registers by virtue of a small excess of pressure above the atmosphere, as already explained in the first section on Heating and Ventilation. In the better class of dwellings, special flues are provided, by which the foul air may pass out; but in the majority of cases it escapes only through incidental outlets, such as openings around the window casings, loosely fitting window sashes, cracks in the plastering and walls, through transoms, and under doors, etc.

The problem of ventilation by this system is always combined with the question of heating. The air is moved solely by heat, which is applied before it enters the room, or immediately after. In the aspiration system, the fresh air may be unwarmed, and the heat for moving it may be applied after it has left the room and entered the foul-air flues.

In this system, the amount of fresh air which may enter the room depends upon its temperature and upon the rate at which heat is lost by cooling, etc. The main object is usually to maintain a certain temperature in the apartment, the fresh air being regarded principally as a carrier of heat. If the cooling process goes on slowly, the quantity of hot air admitted must be reduced, regardless of the needs of ventilation. Thus, this system operates so as to provide the greatest supply of fresh air in very cold, windy weather, and the least in moderate, still, and humid weather, just the reverse of what ought to be the case.

This evil may be remedied by lowering the temperature to such a point that the whole volume of air required for ventilation may be introduced without carrying any more heat than is needed to supply the regular loss. In many cases, a large volume of air will be required at a very moderate temperature. It is not practicable to supply this with ordinary forms of heating apparatus, because they do not contain the requisite area of heating surface. It is much easier to heat a smaller volume of air to a high temperature; the desired volume and temperature may then be obtained by mixing it with cold air in proper proportions.

1975. The only way by which proper and satisfactory ventilation can be secured in the natural draft system is by employing this method of mixing. The volume of the air supply can then be kept nearly uniform, while the heat can be varied as much as desired.

The most conspicuous and serious defect of the system, however, is its weakness or lack of motive force during mild weather. If the volume of air is maintained at a proper standard, the requisite temperature will differ so little from that of the outer atmosphere that the draft will be very weak, usually too weak to operate well. If the mixing method is not employed, then either the heating will be carried too far, or the ventilation will be seriously deficient.

The need of a mixing valve arises mainly from the difficulty of regulating the heat emitted by steam and hot-air apparatus. Where hot water is used, or the vacuum system of steam heating, the heat is under perfect control, and in such cases mixing valves are unnecessary.

VENTILATION WITH DIRECT HEATERS.

1976. Good ventilation is not practicable in a room which is heated by a direct radiator or common stove, unless additions be made, which virtually change the method of heating from the direct to the direct-indirect system.

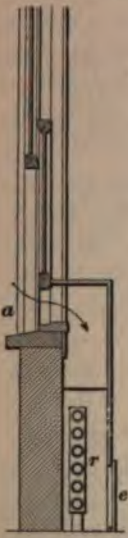

FIG. 781.

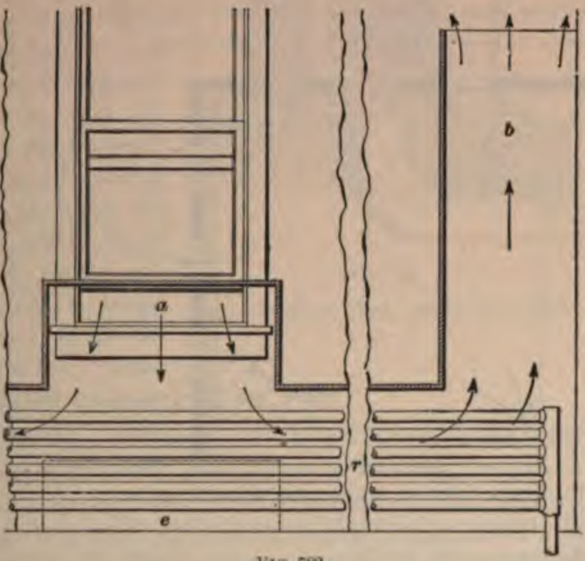

FIG. 782.

In order to secure even a tolerable degree of ventilation, a definite outlet must be made for the foul air. This is more necessary than a special inlet for cold air, because if the foul air can flow out, the fresh air is very apt to make its way inwards in some manner. The best plan is to provide both a positive inlet and outlet, and to supply each with a suitable damper.

If the room does not possess a flue which can be used to carry off the foul air, one must be provided in some way. Usually a flue of tin or wood can be run up alongside one of the interior walls, through the floors, and into the attic. The lower ends or inlets of such flues should open within a foot of the floor.

1977. A practicable method of modifying an ordinary direct-heating system so as to get a fair amount of ventilation, is shown in Figs. 781, 782, and 783. The room is heated by means of pipe coils running along the outer walls. To secure ventilation, the coils are enclosed as shown. Fresh air is taken in through the windows at *a*, and after passing along over the hot radiator pipes *r*, is delivered through the vertical flues *b* into the upper part of the room at the corners *b'*, as shown in Fig. 783. The flues *b* should be about 8 feet high, and should be located in the outer corners of the room, as indicated in Fig. 783. The foul-air outlets may be located along the inner walls, as shown at *c*.

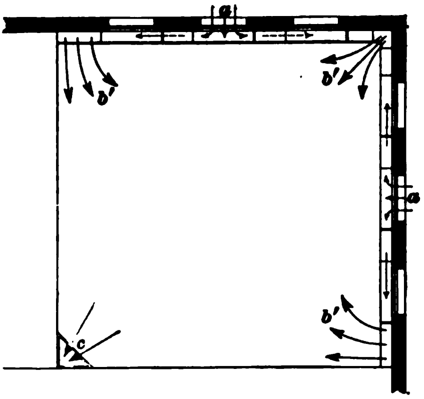

FIG. 783.

In order to heat the room before it is used, and without admitting any fresh air, a door should be provided in the pipe casing, at about the middle of its length, and at the level of the floor, as shown at *e*. This door being opened and the window closed, a good circulation will ensue and hasten the warming process.

Ordinary direct radiators may be treated in the same way; usually, however, it is easier to cut a hole through the wall, and convert them into indirect apparatus, as described in connection with Fig. 787.

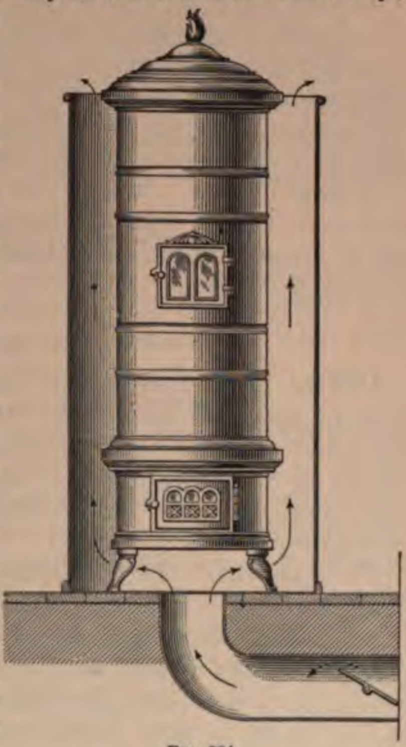

FIG. 784.

Where an ordinary stove is used for heating, the ventilation may be provided for by enclosing the stove in a jacket of sheet iron or zinc, and connecting the space between them with a fresh-air duct in the floor, practically as shown in Fig. 784. It is difficult to arrange a mixing valve in this case that would repay one for the expense incurred. The temperature must be controlled by regulating the fire. Of course an adequate and properly arranged outlet for foul air must be provided, as in all other cases.

FORCED BLAST.

1978. The use of a fan to create an excess of air pressure, or **plenum,** in the interior of a building makes it practicable to secure perfect ventilation at all times, regardless of wind or weather. The certainty of its operation, and its ability to furnish more air if required, are features of great value.

Another important consideration is that the fan may be located at any point which may be most convenient, either at the bottom of the building or at the top. It may be placed in another building, even on the opposite side of the street. The system of air supply may be operated from above, in a general downward direction, or in the reverse way, as may be best adapted to the situation.

The heating apparatus employed in conjunction with a fan may be of any variety desired, either steam or hot water, or hot-air furnace. The use of a forced blast enables the heaters to operate with the maximum degree of efficiency, and to accomplish the work required with the minimum area of heating surface.

FANS AND MOTORS.

1979. It has been pointed out, in the second section on Heating and Ventilation, that there is a great difference in value and efficiency between centrifugal fans and propeller wheels or disk fans; and that the latter variety are so inferior that their use for ventilating purposes can not be recommended.

These fans have one radical defect, which is a serious one and practically incurable. When in operation, those parts of the vanes which are near the rim move very swiftly, driving the air forwards with considerable force; while the central parts move so slowly that they are unable to prevent the air which is thus pressed into the delivery flue from flowing backwards through the wheel and escaping. In consequence of this back flow at the center, they are incapable of producing or maintaining any considerable pressure. Of course the central part of the wheel may be closed, but in any large building the diameter must then be so large as to become objectionable.

In selecting centrifugal fans, small wheels and very high speeds should be avoided, because they are very liable to be noisy. Large wheels waste less power, and have the advantage of possessing a large reserve capacity, which may be brought into use at any time by increasing the speed.

The use of belting or friction gears for driving fans should be avoided whenever possible. The engine or motor should always be connected directly to the fan shaft. The market is fully supplied with engines capable of running continuously at speeds as high as 800 or even 1,000 revolutions per minute, and the use, for ventilating purposes, of slow-moving engines, connected to the fans by belting, is inexcusable. It involves needless complication of machinery, costs more, requires more care, occupies more space, and is far more liable to break down than the direct-connected arrangement.

COMBINED SYSTEMS.

1980. It is common practice to use the aspiration and natural draft systems together, and in many cases it would be difficult to fix the line of demarcation between them. One system naturally supplements the other, and the combination is usually an advantageous one.

There are many instances, also, in which the exhaust system is used in combination with a pressure or plenum system, both being operated by fans. Under all ordinary circumstances, this combination is not to be recommended. It does not afford any particular advantage, and there are several substantial objections to it. The cost for flues, fans, power, motors, installation, and attendance is greater than in a simple pressure system of equal aggregate capacity.

When the pressure system is used alone, the foul air may be vented at any convenient point where it will not become a nuisance; but if the exhaust system be applied also, then all of the foul-air ducts must be extended and concentrated into one large flue leading to the exhaust fan, thus increasing the expense for pipes and flues.

The exhaust and pressure fans, in that case, handle the same air in succession; consequently, one of them is sufficient to furnish the required volume. In order to do the same work with a single fan, it is necessary only to increase the pressure to the total of that produced by the other two. This may be done by increasing the peripheral speed of the fan wheel, either by enlarging the diameter, or increasing the speed of rotation—usually both. The larger single fan will cost much less than the two smaller ones, and will require less care and attention to maintain it in good order.

The single fan will require only about 65 to 75 per cent. of the power consumed by the other two, the saving being due to the smaller waste by friction. The motor or engine will also cost less than two motors required for the other fans. There is also a considerable advantage in favor of the single fan in the matter of space occupied, and cost of installation.

MIXING VALVES.

1981. These valves are indispensable to the success of any system of ventilation, except where hot water or the vacuum steam system is used for heating; otherwise, there is no practicable way of regulating the temperature, and at the same time securing an unvarying amount of fresh air.

The registers which are commonly used for controlling the admission of air to rooms, having louvres or valves that can be opened or closed, are all wrong in principle and should be discarded. Notwithstanding the fact that they are almost universally used with indirect-heating apparatus of all kinds—steam, hot water, and hot-air furnaces—yet they are radically defective in the most important particular. They do not permit the heat to be shut off without shutting off the supply of fresh air at the same time. Mixing valves, on the contrary, permit the heat to be varied to any extent desired without affecting the volume of the air supply. The ordinary variety of register should, therefore, never be permitted, except in cases where it is actually needed to vary the volume of fresh air admitted, or to entirely shut off the air supply.

In large rooms which are supplied with fresh air at several points, it is desirable that each flue should be provided with a separate mixing valve, so that the temperature of the several air-currents may be varied independently when required. During the prevalence of very cold or windy weather, it is usually difficult to maintain an even temperature on both sides of the room; but if the apparatus is arranged as advised, the difficulty may be overcome by introducing the warm air at a higher temperature upon the exposed side than upon the other.

In hospitals it is usually required that the flues be so arranged that a high local temperature may be maintained at any one of the beds, without regard to the temperature prevailing in the other parts of the ward.

In a plenum system having duplicate flues for hot and cold air, the mixing valves should be located close to the main flues, instead of at the foot of the wall ducts. The tempered air may then be delivered to the vertical flues through single pipes; while, if the latter plan is followed, the lateral branches must be doubled throughout, making an unnecessary expense for flues and unnecessarily reducing the head-room of the basement.

1982. Mixing valves are constructed in a great variety of ways to suit different situations, but the principle is alike in all. Two forms are shown in Figs. 613 and 614, in the second section on Heating and Ventilation. Other forms are shown in Figs. 785, 786, and 787 in the present section.

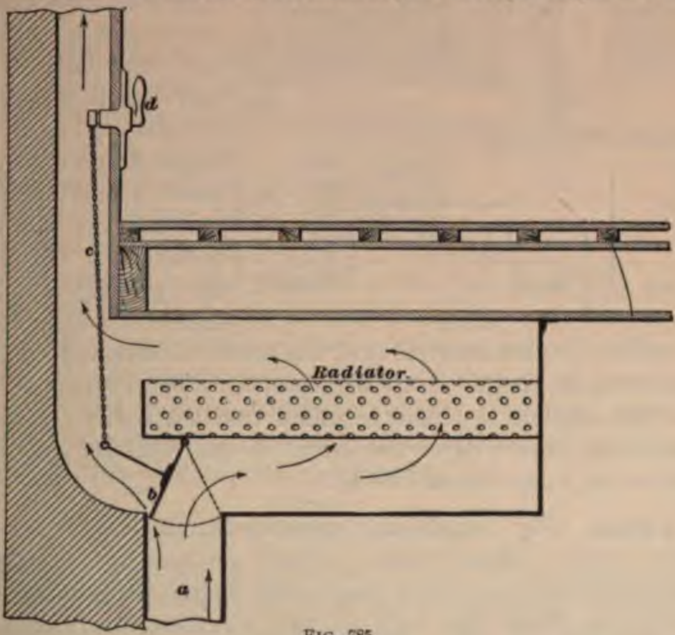

FIG. 785.

Fig. 785 shows an ordinary indirect radiator box, having a cold-air inlet at *a*. A swinging valve *b* is hung near the end of the radiator, in such a manner that it can be made to deflect any proportion of the air-current and compel it to pass over the heating surfaces. The valve is operated by means of a chain *c* and a weighted handle *d*.

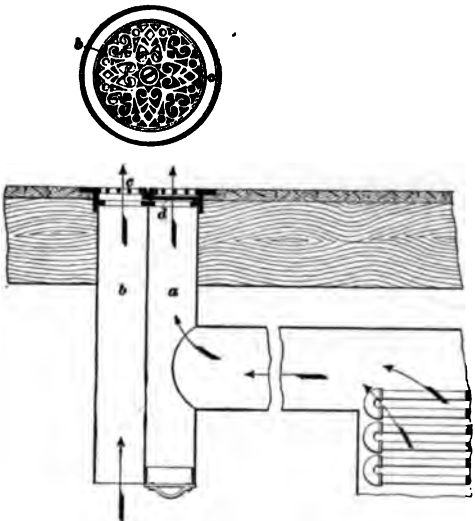

FIG. 786.

1983. Fig. 786 shows a form of rotary valve which is capable of being used in many ways. As shown in the illustration, it is placed at the delivery end of the fresh-air flue, like an ordinary register. The flue is divided by a partition into two channels *a* and *b*, for hot and cold air. The valve *d* is a semicircular plate of metal which revolves about a central pivot and permits the air to flow out through the grating *c*. By means of a key which is inserted in the central slot, the valve is adjusted to any desired position, so as to secure the proper proportion of the two currents. It will be noted that the register in this case must have twice the area of an ordinarv register delivering a like amount of air.

1984. Fig. 787 shows the mode of applying a mixing valve to an ordinary direct radiator or heating coil. The coil is enclosed in a box lined with metal, extending upwards to about the level of the window sill. The box is divided into two parts, the inner one forming a channel for the upward passage of the cold air. The damper *a* is hinged to the partition as shown, and is balanced by a weighted handle on the end of its spindle. When it is desired to heat the room without introducing fresh air, the damper is turned down to its lowest position, shutting off air from the radiator, and the inflow of cold air is stopped by shutting down the hinged cover *b*. The door *d* in the front of the box is next opened, and the radiator then operates by ordinary circulation of the air in the room.

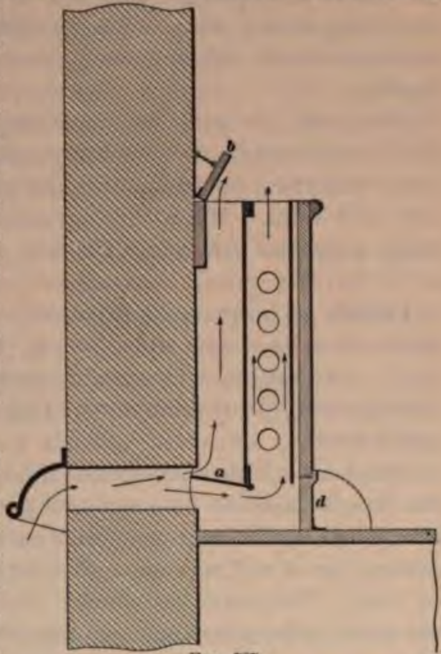

FIG. 787.

The importance of the improvement in ventilation to be made by using these devices is not understood or appreciated, either by the public, who are vitally interested in the matter, or by the architects and others who supply heating apparatus. An eminent sanitarian, Dr. John S. Billings, says of mixing valves: "They should be used much more extensively than is at present the case, and it is in this direction that the most immediate and important improvement of ventilation of dwelling houses, in this climate, can be effected."

FLUES AND DUCTS.

1985. In designing a system of flues for warming and ventilating purposes, it is necessary to carefully consider not only the proper dimensions, but also the efficiency, durability, convenience, and cost of construction.

The velocity of the air-current in wall flues and in branch conduits should always be made lower than in the main trunk pipes, not only for the purpose of reducing the frictional resistance, but to avoid delivering the air into the rooms at a velocity too great to be easily controlled and diffused, and also to prevent perceptible drafts.

When the air is driven by a fan, the velocity may be 20 feet per second in the main flue, and somewhat less in the large branches, but should not exceed 10 feet per second in the wall flues. With the aspiration system, only half of these velocities can be obtained.

1986. The material selected for the construction of the flues must be impervious to air, unaffected by moderate heat or moisture, and should present a smooth surface to the current. It should not be fragile, or easily cracked or punctured.

Wood is an inferior material for this purpose. Although the boards may be tongued and grooved and be painted in the joints, and the entire flue carefully made tight at the outset, yet it will not remain so for any considerable length of time. The wood will shrink and open up great numbers of cracks, thus permitting considerable leakage. The loss of air from this cause may not be a serious matter, but in the case of inlet flues the liability of bad air leaking through into the interior should be fully considered.

These wooden walls may easily be made impervious to air by covering them with cotton cloth, and coating the cloth with oil, varnish, paraffin, or asphaltum. The last named is the best, being very elastic and having no odor. Tar should not be substituted for the asphaltum, nor mixed with it. The cost of the cloth and coating adds materially to the expense, but this may be offset in part by using a cheaper grade of woodwork. The cloth should be applied upon the side against which the pressure comes.

A lining or covering of stout building paper, secured with tacks and good glue, may be used for the same purpose, but is not so durable or tight and is liable to be torn by warping or shrinkage of the boards.

1987. Large flues are sometimes constructed of coarse wire netting, supported on a skeleton frame and coated on the inner surface with plaster. The principal objection to this construction is that the plaster is very liable to shrink and crack, forming numerous small crevices. This tendency is aggravated by the expansion and contraction of the metal framework, caused by changes in the temperature. The plaster is also very easily punctured and broken off.

1988. Flues which are built of brick occupy a great deal of space and are very expensive. Being located in the basement or cellar they generally form a part of the foundation walls, or, at least, are compelled to run parallel with them and conform to their shape and arrangement. As a consequence, there are usually more abrupt angles in brick flues than in metal pipes serving the same purpose. All brick flues should be plastered on the inside in order to present a smooth surface to the air, and especial care should be taken in this particular when the aspiration or natural draft system is to be employed.

1989. Metal flues possess the advantage of being easily made to any reasonable shape, providing round corners and easy curves, a further advantage is that of occupying less room than any other kind. Where they are exposed to moisture, or to the corrosive action of plaster or mortar, their durability may be ensured by coating them thoroughly with asphaltum.

In the plenum system of ventilation, arrangements are often made to carry hot and cold air separately in duplicate flues. Usually the flues are made of equal size, but in most cases this is not necessary, because the volume of cold air required for tempering or mitigating the temperature of the hot-air current is usually considerably less.

In order to determine the relative size of these flues it is necessary to assume, or to plan in advance, the temperature that is to be given to the main hot-air current when the out-door temperature is at its lowest.

ARRANGEMENT OF FLUES.

1990. The general method to be adopted in arranging the main distributing flues (or ducts) and branches in the basement of a building depends upon the system of ventilation to be employed, and upon the arrangement of the heating apparatus—whether concentrated or distributed.

With the plenum system, there are five methods in common use, as follows:

1. The main flue, or duct, is carried along the center line of the building, and lateral branches are extended right and left to the vertical ducts in the side walls. If these are numerous, the aggregate length of the branches is liable to become excessive, causing too much frictional resistance, and entailing unnecessary expense.

2. The main flue is divided into two branches, one of which extends along each side of the building and supplies all the vertical flues on that side. The connections to the wall ducts are then made direct, or nearly so. In many cases this plan is more economical, in the matter of piping, than the previous one.

3. An air-chamber is located in the central part of the basement, and the air is conveyed to the various vertical ducts by means of pipes extending radially from the central chamber to the points desired. This plan is suitable only for small buildings. If the pipes are very long, or are numerous, it is likely to prove an expensive and cumbersome arrangement.

4. The entire basement, or a large part of it, is made air-tight, and is employed as a reservoir for fresh air. This plan is suitable for all classes of buildings where the basement is not required for storage purposes. Where this system is adopted, great care must be taken to make the floor or bottom perfectly water and gas tight, so as to prevent the entrance of moisture or earth gases; all drain and soil pipes must also be rigorously excluded from the rooms used for air storage.

5. A vertical air-shaft, extending from the basement to

the top floor, is located in the central part of the building, horizontal branches, more or less subdivided, being taken off at each story. In buildings of three or more stories in height, this plan is usually an advantageous one.

6. The fan delivers the air into a chamber which is divided into two parts, one for hot and the other for cold air. Each wall flue is connected to this chamber by a separate and independent pipe, and each pipe is provided with a mixing valve which delivers air from either the hot or cold chamber, as desired.

1991. Improper Outlet for Foul Air.—The practice of using the attic of a building for a foul-air receiver, as frequently done in schoolhouses and similar buildings, is highly objectionable. The usual arrangement is to terminate the foul-air flues at the attic floor and permit them to discharge freely into the space above. Sometimes an aspirating shaft is attached to the roof to aid in discharging the foul air, but usually it finds its way out through slatted windows and similar openings. The wind has comparatively free access to the whole space, and while it blows, a considerable difference in pressure is likely to exist at the opposite sides of the room. In many cases, the excess upon one side will be so great as to check the outflow of air from the flues on that side, and even to cause a blow-down.

During windy weather, with such an arrangement, the draft of the flues in the windward half of the building will be much too strong, making it more difficult to heat the rooms properly; while in the leeward half, the outlet flues will work very sluggishly, if at all.

All this trouble could be prevented by connecting each flue to the aspirating shaft; at the same time, the force of the draft would be greatly augmented throughout the entire building. These advantages, however, are deliberately sacrificed, and there appears to be no excuse for such an ill-devised arrangement.

A BAD SANITARY ARRANGEMENT.

1992. The problem of disposing of the sewage matter from schoolhouses is sometimes a difficult one, especially where no water supply is available for water-closets. A system designed to meet the wants of such cases has been introduced within recent years under the name of the *dry-closet* system. This should not be confounded with the well-known *dry-earth* system, which is quite unobjectionable on sanitary grounds.

This **dry-closet** system is operated by an aspirating chimney, usually the same one which draws the foul air from the schoolrooms. The closet seats are located in the roof of a tunnel leading to the chimney, and each seat is provided with a cover which is intended to be kept closed when not in use. The liquids are sometimes drained off, but the solid matters remain on the floor of the tunnel, and are gradually dried by the current of air which passes over them to the chimney. At the end of the school term, the deposits are saturated with kerosene, and then destroyed by fire.

The foul air from the schoolrooms is drawn directly through the tunnel; consequently, whenever a blow-down occurs, not only will the foul air be driven back into the rooms, but the noxious effluvia of the tunnel will be carried back with it.

As drying and evaporation can take place, in this case, only by absorbing heat from the air-current, it is evident that the temperature of the foul air will be lowered somewhat, and the draft of the chimney will be weakened correspondingly. Sometimes a small grate fire is maintained at the entrance to the tunnel or the base of the chimney, to maintain the draft in mild or warm weather, when the heating apparatus is not in use.

In some cases, a separate chimney is provided for the dry-closet, and the air is taken only from the room containing the apparatus. The result of a blow-down, however, is the same as in the previous case, except that the communication with the interior room is a little less direct

The seats in these dry-closets are always at a higher level than the inlet for air; consequently, the effluvia in the tunnel always tend to flow out into the room wherever a cover is raised. Usually the chimney draft is sufficient to counteract this tendency and prevent any outflow, so long as only one or two covers are opened; but when all the seats are in use at the same time, as often happens, at recess and other occasions, the draft is wholly inadequate. It is then found that while air flows inwards at a few of the seats nearest the chimney, the vile tunnel air flows out unchecked at the others.

1993. Another very serious objection to this system is that much of the fœcal matter is reduced, by drying, to the condition of dust, and is carried up the chimney. If this matter happens to be infested with the germs of contagious diseases, these also are dried and projected into the atmosphere. In fact, matter is thus carried into the air that ought to go into the earth. All dust eventually descends to the level at which people breathe; thus, the effect of this apparatus is to disseminate filth and disease germs broadcast over the surrounding country. The dry-earth system, in which all fœcal matter is mixed with dry absorbent materials, is free from all such objections.

The dry-closet system of heating and ventilating schoolhouses, as it is done to-day, is a disgrace; it is one of the worst disease breeders that can be devised in schoolhouse construction.

PRACTICAL VENTILATION.

1994. The requirements for the successful ventilation of the various classes of buildings which are occupied by human beings are alike in principle in all cases, and have been fully considered in the preceding chapters. The ventilating engineer should bear in mind that ventilation is a sanitary necessity, and should realize that the physical health of those who occupy the premises depends in a large degree upon the skill and faithfulness with which he plans and executes his work. His patrons have in most cases very hazy and often mistaken ideas of what is necessary and proper, and consequently are unwilling to expend sufficient money to secure proper ventilation. He has, therefore, to protect these people against their own ignorance and parsimony.

Considering the matter from a sanitary standpoint, the problem of ventilating the ordinary dwelling, containing from four to eight rooms, must be regarded as the most important, because the vast majority of our people are housed in that kind of building, and are vitally affected by the conditions prevailing in them.

Schoolhouses come next in importance, being occupied by large numbers of children for from four to six hours per day. Children are much more susceptible than adults to insanitary influences, and must therefore be guarded with the utmost care.

Next in importance are the manufactories, containing large numbers of people engaged in labor for from eight to twelve hours per day. Public buildings, such as theaters, churches, audience rooms, and legislative halls, although they receive the greatest share of public attention, are really of less importance to the sanitarian, because they contain comparatively a smaller portion of the population, and are occupied only for short periods of time.

The chief impediment to good domestic ventilation is the expense of the apparatus. Much of the apparatus now on the market is needlessly complicated and costly, and is encumbered with numerous "attachments" which are more profitable to the vendor than the purchaser. There is urgent need for apparatus which is both efficient and cheap, and which can be operated without special skill. There are no serious mechanical difficulties in the way, and the reason why such apparatus is not readily obtainable is because the matter has not received the same degree of attention that has been given to other departments of mechanics. The application of forced draft to dwellings is hardly begun as yet, but it is in this direction that improvement is chiefly to be expected.

VENTILATION OF DWELLINGS.

1995. The number of people contained in an ordinary dwelling is usually quite small, while the area of windows and other cooling surfaces is relatively larger than in any other class of buildings. Consequently it happens, in many cases, that the volume of air required for respiration is less than that needed to maintain the temperature.

It is impracticable to ventilate a dwelling in a proper manner while *direct* heaters of any kind are used for warming it. The heaters, whether stoves or radiators, must be converted into *direct-indirect* or *indirect* apparatus; and the foul air must be vented positively and continuously. The inlets and outlets of each room must be managed so that there will be no considerable difference of temperature in any part of it.

These results can be attained only by employing some system of aspiration, mechanical ventilation being assumed to be impracticable on account of expense. Foul-air ducts of suitable size, and having sufficient height to draw well, must be provided; they are, in fact, indispensable.

These ducts should be brought together and connected into a good chimney. The smoke pipe from the kitchen stove or the heating apparatus should extend up through this chimney such a distance that there will be no chance of having a poor draft for the fire. The pipe inside of the chimney should be made of cast iron, to withstand corrosion, and it should be braced so as to stand in the center of the flue rather than at one side. It is better to make one large flue, with a smoke pipe inside of it, than to build a pair of flues, one for foul air and the other for smoke. In all but the smallest dwellings, two such foul-air chimneys should be provided, one taking the smoke-pipe from the kitchen range, and the other from the furnace or boiler. This permits the foul air to be disposed of with a minimum amount of piping.

The doors and windows should be made as nearly *air-tight* as possible, so that cold air can not enter the building except through the proper channel, that is, through the heating apparatus.

1996. One of the chief difficulties to be found in securing a proper distribution of warm air in the several stories of a dwelling is the draft that always exists to a greater or less extent on the **stairway.** An upward current of considerable force prevails here at all times while the heating apparatus is in use, and if there is any mode of escape for air at the top, this draft will be so strong as to interfere with the proper suction of the foul-air flues. While this trouble may be avoided by enclosing the stairs and placing doors at the foot or head, this remedy is usually so objected to that it may be dismissed as impracticable.

If one side of the hall or stairway consists of a cold outer wall, it will be difficult to warm the space satisfactorily, especially if there are large windows in any part of it.

There will be a warm up draft in one part and a cold down draft in another part, and it is advisable in such a case that all rooms opening into the hall be shut off from it by means of doors. Curtains or draperies can not be used successfully for this purpose, unless they are made extraordinarily heavy and tight—too heavy, in fact, to be desirable.

If the hall is located in the middle of the building, so that it is warm on both sides, the stairway draft may be utilized to operate the ventilating system. The foul air may then be drawn out from each room into the hall through the space under the doors, these spaces being made of proper size to serve as foul-air exits.

At the top of the stairway the air should be discharged through an aspirating shaft, and not through a skylight or ventilator. The draft of this shaft should be made as positive as possible by conducting the principal smoke pipe through it. If the skylight is used for this purpose, a current of cold air is likely to enter at one part of the opening, while warm air flows out of the remainder; thus, the cold air will pass down the stairs, making very unpleasant drafts.

When the hall is employed in this manner, all the larger rooms, especially those on the first floor, should be provided with additional foul-air outlets. An open fireplace serves excellently for this purpose, provided that the opening into the chimney is not too large, or too far above the floor. A fireplace, as explained on another page, is a poor contrivance for heating purposes, but it can be made a very useful assistant to ventilation.

1997. In **dining-rooms** and **parlors**, where gas burners or oil lamps are used for illumination, it is a good plan to enclose the lights in glass, and provide them with a special draft tube connected to the foul-air flue. This arrangement not only disposes of the products of combustion, but it will, if properly constructed, add considerably to the brilliancy of the light. It also furnishes a local vent which serves admirably to clear the room of the fumes of cigars, etc.

1998. A common method of ventilating **sleeping rooms** is to provide two openings into the hallway, the door being raised an inch or more above the floor, and the transom being opened above it. This device, however, is inoperative, because there is no force tending to drive the air either way through these openings. If any fresh air reaches the occupant of such a room, it will be by leakage through or around the window. If the window is open, and the weather is quiet, the air from the hall is likely to pass through the room and escape at the window, thus making the chamber a passageway for vitiated air. The air in the hallways is rarely good enough for sleeping rooms, and, as a general rule, should be excluded.

1999. The **bath-room** should be thoroughly ventilated and warmed. As usually constructed, in the smaller class of dwellings, the bath-room is but little larger than a closet; and when a warm bath is taken, the air is quickly vitiated, to a serious degree, by the combined effects of moisture, heat, gas burners, and respiration. Where no positive ventilation is provided, this bad air, in conjunction with a warm bath, is very exhausting.

Bath-rooms should never be warmed by any device that will vitiate the air, such as gas or oil stoves, or water heaters having no connection to the chimney. A very common method of warming, and at the same time the worst that was ever devised, is by means of a register in the floor, opening into the kitchen or other warm room below. This converts the bath-room into a mere foul-air chamber for the relief of the kitchen.

One of the best ways of warming a bath-room, where the house is provided with a hot-water supply, is to locate the **kitchen boiler** in it. This arrangement has several advantages over the ordinary one of placing the boiler close to the range. It not only makes the bath-room abundantly warm on all occasions, but it relieves the kitchen of a great deal of surplus heat, and thus mitigates the discomfort of those who have to work there. The increased elevation of the boiler also improves the circulation in the hot-water apparatus.

2000. The **water-closet** should be provided with a special ventilating flue, or *local vent*, and care should be taken to ensure a draft in it that will never be reversed. This pipe should take air from under the seat, and should, if practicable, discharge into the kitchen chimney. If this can not be done, then the flue should run to the top of the building independently of all other pipes, and also be provided with a gas burner or other artificial heat to secure a positive draft at all times. It should not be connected into the ventilating pipes of the drainage system. In the summer time, the interior of the house is likely to be cooler than the exterior, and if the draft is not made positive in some way, it will be reversed, thus causing the very mischief which it was designed to prevent.

2001. All **clothes closets** should be ventilated, especially those which receive undergarments or soiled clothing. Dirty clothes or bags containing them should never be permitted in the same closet with clean ones. The openings from these closets should be protected with fine screens to keep out moth millers, etc.

2002. The **kitchen and laundry** should be ventilated independently of the other parts of the house, and if there is any door opening directly from them into the hall or stairways, it should be made practically air-tight, otherwise the odors of cooking, etc., will pervade the halls and upper rooms.

The **range** should be provided with a hood of liberal dimensions, to carry off the hot air and vapors. The vent pipe should connect to a good ventilating flue; but, if this is not practicable, it may be run up to the roof independently. Sometimes it is necessary to provide this pipe with a damper, so that it may be closed when the fire is low, or during stormy weather.

2003. The ventilation of the **cellar** is a matter of great importance to the health of the family, yet in the majority of dwellings no provision is made for it, and it is not even supposed to be necessary. As already pointed out, in Art. **1924,** the cellar is usually a reservoir of earth gases and unwholesome emanations from stored vegetables, coal, etc., which should not be permitted to pass up into the living rooms.

The necessary ventilation can be secured by running a flue from the *highest* point in the cellar, usually the top of the stairway, up to the roof, placing it in some interior wall where it will be reasonably warm. The proper size for this flue depends upon the character of the cellar—whether wet or dry—and the nature and quantity of materials stored in it. Ventilation is needed most when the place is both warm and moist, because fermentation then proceeds with the greatest freedom, and molds and fungi flourish vigorously. It is not advisable to merely make an opening into one of the chimneys for ventilating purposes, because it will probably spoil the draft of the stove or heating apparatus connected to it.

The presence of a furnace or boiler in a cellar helps to ventilate it, by passing a considerable quantity of air through the fire and up the chimney. The quantity thus removed, however, is quite insufficient unless the cellar be small, very clean, and unusually dry. It should be noted that in this case the air is taken from the floor, instead of the ceiling as it should be.

2004. The **first floor** in a dwelling should be made gas-tight, in order to prevent the cellar air from passing through and mingling with the air in the living rooms. This is best done by laying the floor in two thicknesses, with a thick layer of tarred paper between them. Ordinary building paper is quite inferior to the tarred material for this purpose. This floor should extend to the outer walls of the building and be made air-tight around the edges, so that no air can possibly pass up from the cellar into the spaces between the studding or furring strips.

In the cheaper class of frame dwellings, it is a common practice to leave these spaces open, so that they form flues up which the cellar air passes to the attic without restriction. The ventilation thus afforded, although quite unintentional, has probably saved the inmates of such dwellings, in a multitude of cases, from the sickening effects of bad cellars that otherwise would have been deadly. The existence of these flues or passages is highly objectionable on another account, namely, that they permit heat to escape through the walls with undue rapidity. All circulation of air within them should be prevented, either by putting in tight horizontal partitions at short intervals, or, better still, by filling the spaces with mineral wool or other non-conducting materials. Brick and mortar are not desirable for this purpose, because they absorb a great deal of moisture, and tend to rot the woodwork.

FIREPLACES.

2005. The open fireplace is an exceedingly inefficient form of heating apparatus. It passes so much air up the chimney that the heat radiated from the fire is quite insufficient to warm the fresh air rushing into the room to take its place, to a sufficient degree to be comfortable. It is impracticable to warm rooms satisfactorily by means of the open fireplace, if the external temperature is much below 32°.

When the thermometer falls to 10° or lower, it appears as if the room becomes colder the more the fire is made up, until it seems as though the inmates would eventually be frozen. In some cases, fireplaces are constructed so as to warm the fresh air before entering the room, by passing it through a heating flue; but all such arrangements are faulty in principle, and are unable to remedy the trouble to such an extent as to be of any value. The fresh air is delivered so near to the fireplace that it passes almost immediately into the fire, and thus leaves the remoter parts of the room to freeze as before.

The ordinary fireplace wastes 90 per cent. or more of the heat, and even the most improved varieties are believed to waste not less than 80 per cent. of the heat given out by the fuel. It is obvious, therefore, that their use is restricted to places where expense is not objected to, and to localities where the temperature does not descend below the freezing point.

They may be employed to good advantage, however, in colder climates, by using them as auxiliaries to the principal heating apparatus, putting fires in them only when the weather is extremely cold.

SUMMER VENTILATION.

2006. During warm weather, when the heating apparatus is not required, a building can be abundantly flushed with air by opening the doors and windows. But it is necessary, nevertheless, to make provision for proper ventilation during stormy weather, when all outer doors and windows must be closed.

To accomplish this, a register should be provided near the ceiling of each room to provide for the escape of foul air, in addition to that near the floor, because the latter is practically inoperative at this season. These top or ceiling registers are suitable only for summer use, and should be tightly closed at the end of the season when the heating apparatus is started up.

Particular attention must be given to the ventilation of the cellar. Every window should be kept open continuously, and the outer doors should never be closed except during storms. Strict cleanliness should be enforced at all points, and the air should be kept as sweet and fresh as in the living rooms. If it is practicable to admit sunlight, it should always be done.

2007. The arrangements usually employed to shut out the excess of sunlight from living rooms and chambers are fatal to good ventilation. Draped **curtains** are usually hung so high and so close to the casings that they prevent the flow of air either way through the upper half of the window. The rolled curtains or shades, as commonly applied, are equally obstructive. All such curtains should be hung so that there will be a clear space of 1½ or 2 inches above the roller, for the passage of air. The top sash being lowered, the curtain can then be pulled down to the bottom without shutting off the air supply.

In applying **screens** of wire cloth or mosquito netting, to keep out insects, etc., it should be borne in mind that the flow of air through those materials is only about one-fourth of that through a clear space of equal area.

EXAMPLES OF VENTILATION AND HEATING.

DWELLINGS.

2008. Fig. 788 shows a good arrangement of heating and ventilating apparatus in a small frame dwelling. This house represents a class which is very numerous in the country and suburban districts. It is two stories high, except the part containing the pantry, which is a one-story addition.

The heating is performed by means of a hot-air furnace *d*, and the ventilation is secured by an aspirating chimney *f*. The draft in this chimney is aided by the heat emitted from the furnace smoke-pipe *c*, which passes up through the center of it. In order to be durable, this pipe must be made of cast iron; common wrought-iron or galvanized pipe is worthless, being quickly destroyed by corrosion. The smoke-pipe from the kitchen range should be connected into this pipe, so as to aid ventilation when the furnace is not in use.

The hot-air registers are located near the ceiling and in the extreme outer corners of the rooms; the foul-air outlets into the chimney are made near the floor. A second set of outlets near the ceiling are provided for use in summer time. It will be noted that the vertical hot-air ducts are carried up inside the room, instead of between the studding in the interior of the walls. The reason for this is that the walls are usually too thin to permit the use of a proper-sized flue, or to permit it to be properly protected against loss of heat. In the arrangement shown, a layer of good non-conducting material one inch thick is interposed between the wall and the ducts, as shown at *a*, *b*, and *c*. The other surfaces of the ducts are merely painted, or papered, or encased with thin wood, so as to present a satisfactory appearance, and also protect them from injury.

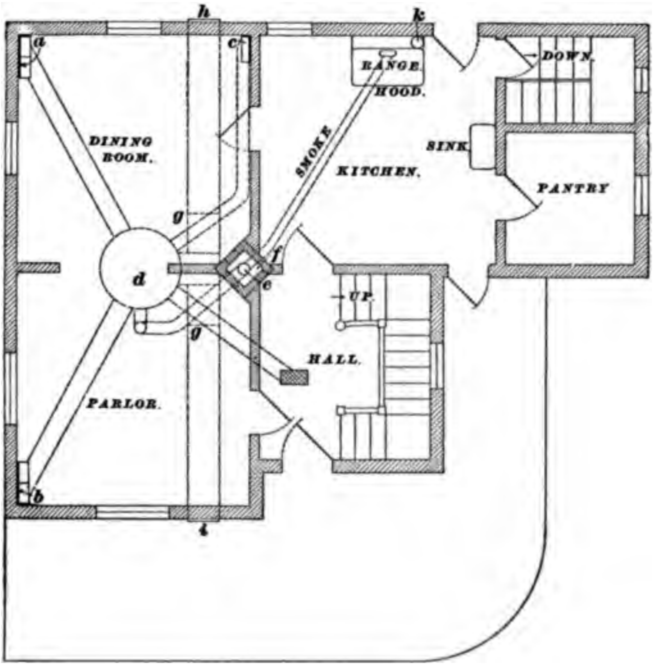

FIG. 788.

The best non-conductors for this purpose are either coarse wool or hair felt, or thin slabs of magnesia, sometimes called "mackite." If these are too expensive, a good sound pine board, free from knots or resinous spots, may be used instead. Paper will not afford sufficient resistance to the escape of heat, unless it be applied in many thicknesses, forming a layer at least half an inch thick. Common mortar or plaster is of very little use for this purpose; wood is far superior.

2009. Instead of connecting each vertical duct to the furnace by a separate pipe, as furnacemen usually insist upon doing, only one leader is used to supply each group, and it should be covered with non-conducting material. The second-story flues are throttled at the bottom where they join the leader, so that they will not take an undue share of the hot air.

The hot-air register in the hall is placed in the floor, instead of in the wall, so that it may serve conveniently as a foot warmer, etc. The draft at this register is likely to be good, unless there is a considerable infiltration of cold air through the walls and around the outer door and windows.

The kitchen range is provided with a hood and a ventilating pipe *k*, which extends upwards to a point above the main roof and is provided with a proper cowl. This pipe should be provided with a damper, to prevent a back-draft of cold air during the night time, when the fire is low, and to prevent loss of heat during cold weather. This arrangement adds greatly to the comfort of the kitchen, and more than repays for the extra outlay incurred.

2010. The cold-air flue extends from the front to the rear of the house, and is provided with a tight shutter or slide at both ends, *h* and *i*. It is carried along overhead under the floor beams, and is connected to the base of the furnace by inclined pipes *g*, which dodge the hot-air pipes and the smoke-pipe.

In order to make a success of this system of ventilating and heating, the building must be made as nearly air-tight as possible. The walls must be made impervious at all points, and the circulation of the air between the joists and floors must be stopped. The windows and outer doors should be made wind-tight by means of packing or weather-strips. It is essential, also, that the aspirating chimney *f* should be extended well above the main roof, and the top properly constructed, or provided with a cowl, so that the wind will aid rather than impede the draft. The success of the whole system depends upon having a good draft in this chimney.

2011. Hot-air furnaces are always objectionable, because

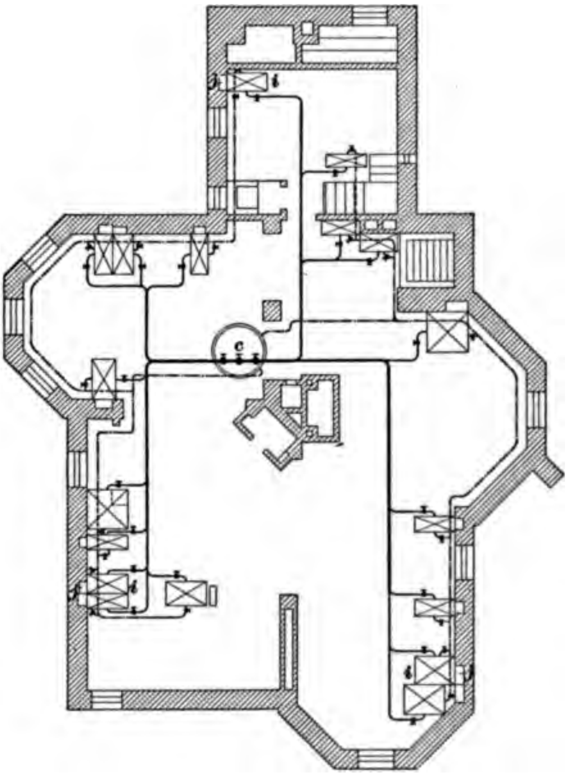

FIG. 789.

they vitiate the air with gas to a greater or less extent; a much better quality of air can be secured by using a hot-water heater instead. The radiating coils may all be concentrated in one box, which is located in the same place as the furnace, and the warm air may be distributed by the pipes shown. Fairly good results may be achieved by using radiators in each room, but in this case each radiator should have an independent supply of fresh air, and should be encased so as to deliver the warm air at the top of the room, as described in a previous article.

2012. Figs. 789 to 793 show the arrangement of flues and apparatus for ventilating and heating a suburban residence of moderate size. The ventilation is effected by an

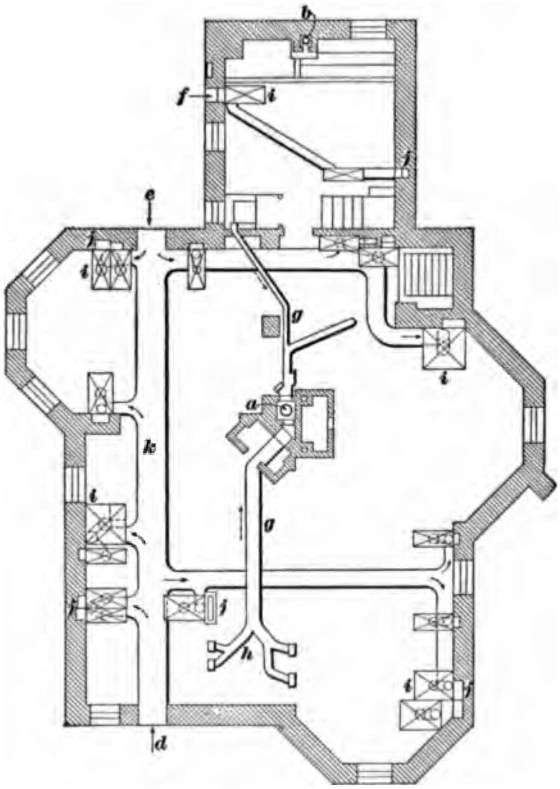

FIG. 790.

aspirating chimney, and the heating is performed by indirect hot-water apparatus.

The aspirating chimney *a* is 25 inches square inside, and the draft is aided by a 10-inch smoke-pipe from the boiler, which passes up through it. Another aspirating chimney *b* is provided in the kitchen for the use of the rear part of the house. This latter chimney is made 18 inches square, and the smoke-pipe within it is 8 inches in diameter. The water closets are local-vented by this chimney instead of the other,

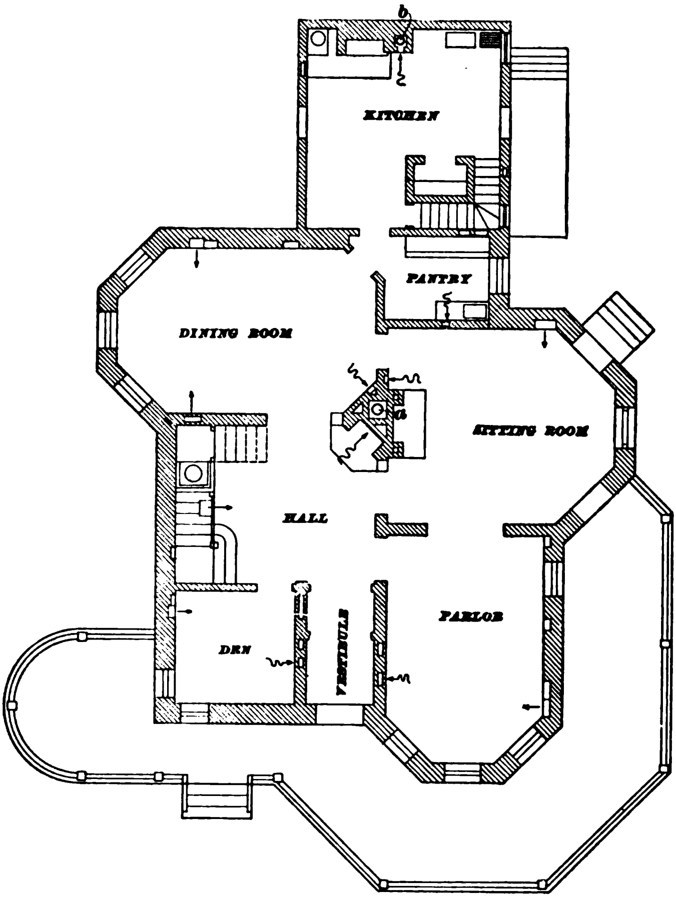

FIG. 791.

so that effective ventilation may be had at all seasons of the year. Figs. 789 and 790 are both basement plans, one showing the radiator stacks *i* and hot-water piping, and the other showing the cold-air ducts *k* and the main foul-air flues which

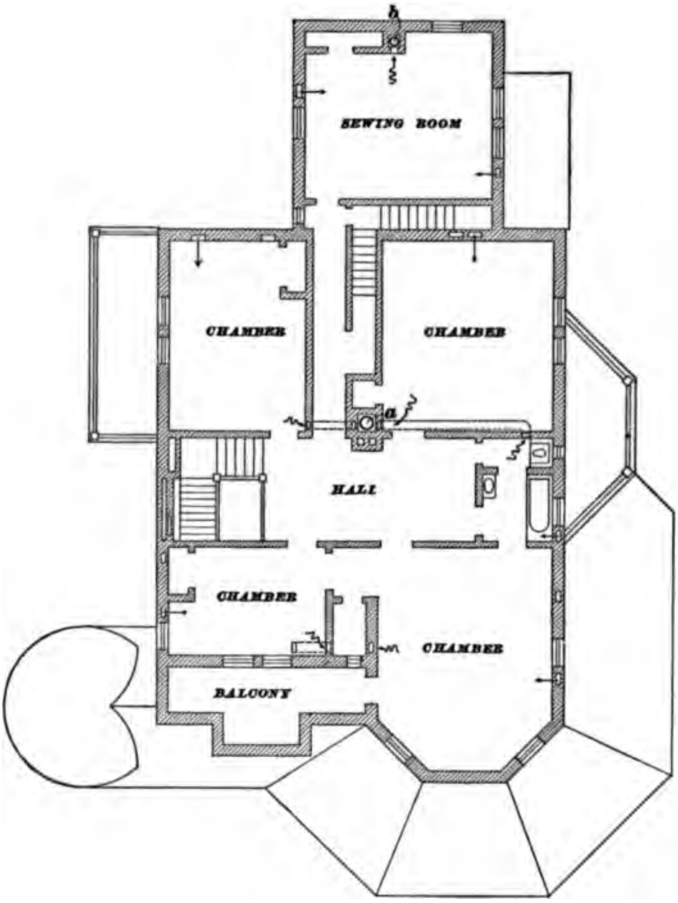

FIG. 792.

discharge into the central chimney. The flow pipes are shown in solid lines, while the returns are indicated by dotted lines. The boiler is shown at *c*.

The cold air enters through windows at *d*, *e*, and *f*, the last named being for the radiators in the rear. It then enters the casings of the indirect stacks on their under side, passes up between the radiator surfaces, and flows into the several rooms through the hot-air flues *j* which are built in the walls. All the foul-air ducts from the rooms on the first and second floors are led downwards to the basement, where they connect with the main flues *g* and *h*. On the third floor, however, they discharge directly into the chimney, as shown in Fig. 793. All the hot-air inlets are located about 6 inches below the ceiling, and the foul-air outlets are placed on the opposite side of the room, just above the baseboard. It will be noted that the warm-air registers are located in cold outer walls, while the foul-air ducts are run only in warm interior walls.

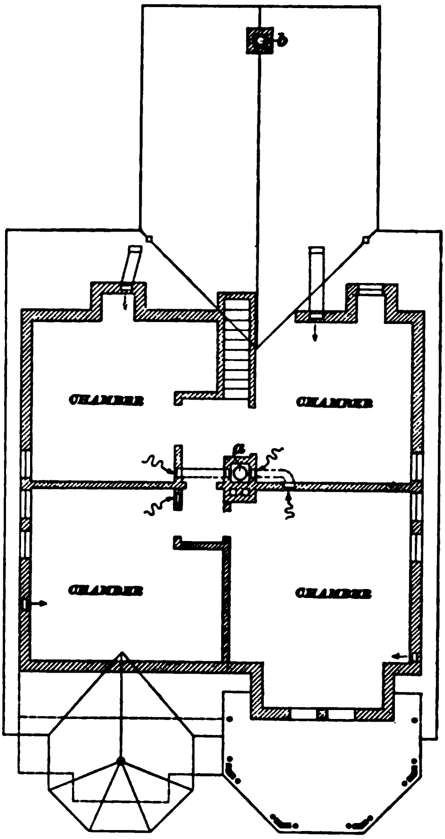

FIG. 793.

SCHOOLHOUSE.

2013. Figs. 794 and 795 show an ordinary two-story schoolhouse, of eight rooms, ventilated and heated by modern methods. The fresh cold air is taken down through a shaft *a*, which extends sufficiently far above the roof to ensure its not being seriously interfered with by the wind. It is then driven

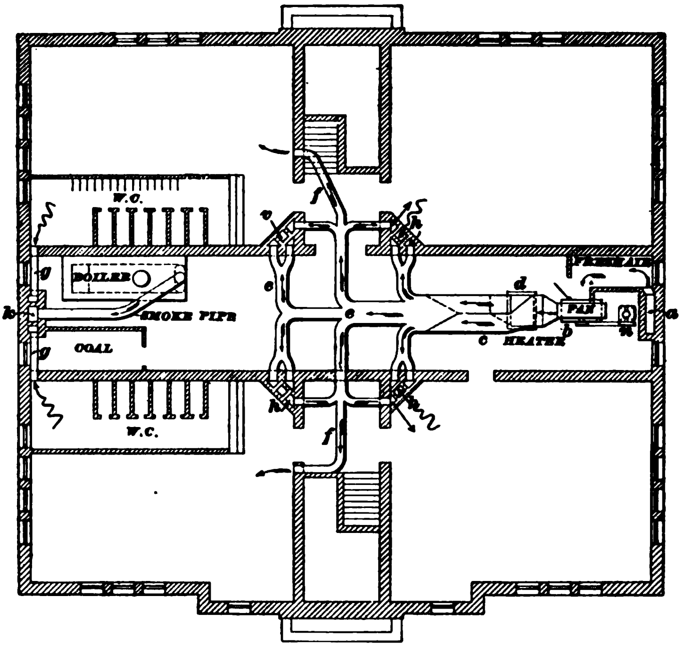

FIG. 794.

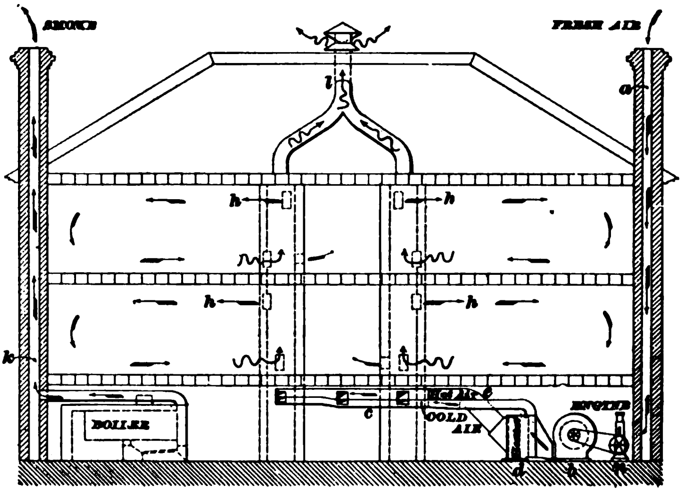

FIG. 795.

by a centrifugal fan *b* through a heater *d*, and is delivered to the vertical ducts *h* by the pipes *e*; the foul-air vent is shown at *v*. A part of the air passes around the heater and is delivered cold to the wall ducts by the pipes *c*. The hot-air flues for the various rooms are made separate, and each one is provided at its foot with a mixing valve, so that the temperature of the air supplied to any room may be quickly changed without affecting any of the others, and without diminishing the volume of the air supply. Both the heating and ventilating flues are located in the inner corners of the rooms, the hot-air register being near the ceiling, and the foul-air outlet near the floor.

The basement rooms containing the water-closets are supplied with air by means of the pipes *f*, the foul air being taken out by the flues *g* which run up alongside the smokestack *k*.

All the other vent flues are run to the attic separately, and are there united into a single stack *l*. No cowl or other protection is needed over the top of this outlet, if provision is made at its base to drain off any rain that may fall into it.

No radiators are used at any point, except in the main corridor on the first floor, and two of these are arranged just below the level of the floor, to serve as foot-warmers. All the other heating surface is concentrated in the heater, where it can operate with the greatest efficiency. The engine *n* is shown attached directly to the fan, so that there are no belts to cause trouble or require attention.

The attic floor is lined with thick paper and carefully made air-tight, both to prevent any waste of air, and also particularly to guard against the loss of heat from the rooms below.

2014. The arrangement of hot-air registers here shown is suitable only for rooms of moderate size. In large rooms, the cooling effect of the outer walls is likely to be so great as to produce a considerable drop in the temperature, making the remoter parts of the room quite uncomfortable. In

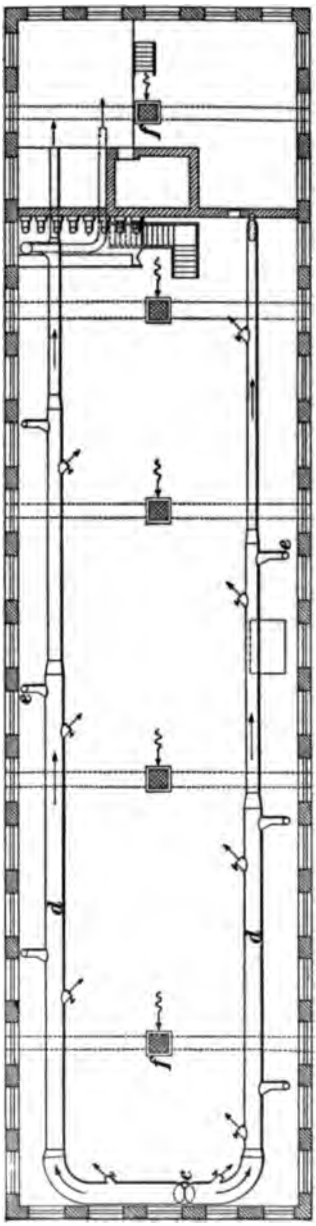

FIG. 796.

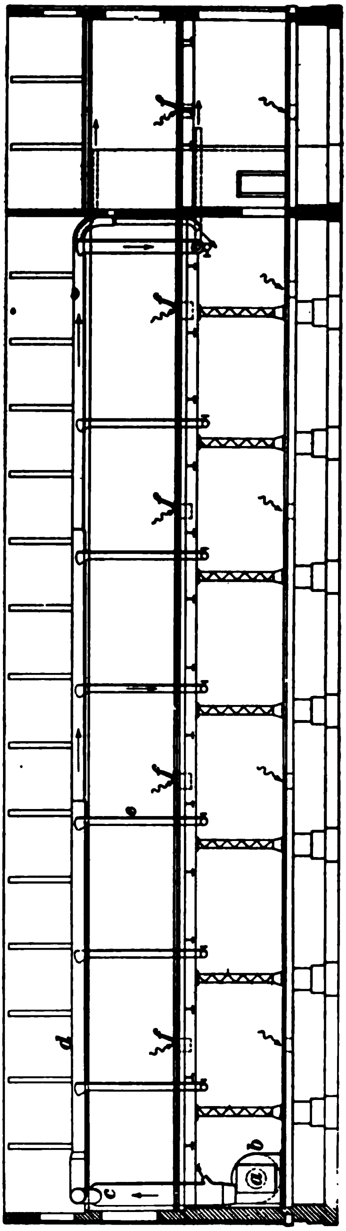

FIG. 797.

such cases, the registers must be increased in number, and the warm air must be delivered more directly to the cold part of the room.

Where this can not be conveniently done, the deficiency in heat may be made up by running pipe coils along the outer walls, especially under the windows. Coils are better for this purpose than radiators, because the heating surface is distributed over a greater space. Each line of pipe should be provided with valves at both ends, so that any number of them may be shut off if desired; otherwise, they are liable at times to give off too much heat, and become a source of great discomfort to the students sitting near them.

The **clothes closets** or "cloak rooms" should be separated from the class rooms, and should be thoroughly ventilated, independently of all other rooms. They should also be so arranged that they may at times be tightly closed for purposes of disinfection.

MANUFACTORY.

2015. Figs. 796, 797, and 798 show a manufacturing establishment, two stories high, 50 feet wide by 200 feet in length. The fresh-air supply is driven through a steam heater *a*, having 4,000 square feet of tube surface, by a fan *b* which has a wheel 72 inches in diameter and 33 inches wide. The hot-air mains are carried up to the roof and are run along horizontally just above the tie-beams of the trusses. Vertical branches are carried downwards to the first and second stories at moderate intervals, and are provided with gates at their outlets.

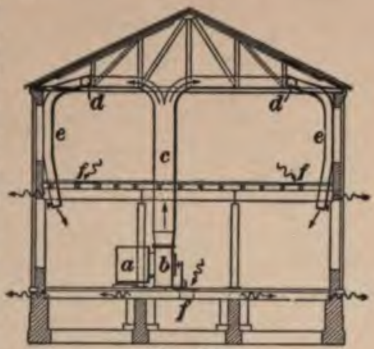

FIG. 798.

This arrangement of piping prevents any interference with shafting and machinery, and the air being delivered at the top of the room, all stagnation or accumulation of foul air is prevented. The foul air is vented through ducts under the floor, which discharge through openings in the outer walls.

The fan takes air from the outside of the building during working hours, and from the inside at other times, when there are but few people in the building. The heating is done principally by the exhaust steam coming from the shop engines, live steam being used only during the night.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the questions and examples contained in the following pages are divided into sections corresponding to the sections of the text of the preceding pages, and that each section has a headline which is the same as the headline of the section to which the questions refer. No attempt should be made to answer any questions or to work any examples until the corresponding part of the text has been carefully studied.

PRINCIPLES OF HEATING AND VENTILATION.

(ARTS. 1334–1485.)

EXAMINATION QUESTIONS.

(803) (*a*) Of what is the atmosphere composed? (*b*) Are the gases simply mixed, or do they form a chemical compound? (*c*) Which of the atmospheric gases supports combustion?

(804) What class of thermometers would you employ to ascertain temperatures greater than 1,000° F.? Explain their action.

(805) How would you proceed to test a mercurial thermometer?

(806) (*a*) How can steam be heated to a temperature greater than that given in the steam tables without increasing its pressure? (*b*) What is the name of steam so heated?

(807) A straight wrought-iron pipe 250 feet long is fitted up when its temperature is 60° F.; how much will it expand if filled with steam having a pressure of 60 lb. by the gauge?

Ans. 5.0820 + in.

(808) (*a*) What do you understand by a diathermic body? (*b*) Mention some matter which is almost perfectly diathermanous. (*c*) What is the most diathermanous solid you can think of?

(809) Mention six forms of resistance which air encounters as it flows through a series of pipes or flues.

(810) Mention two methods of vaporizing liquid.

(811) Explain clearly how a downdraft may be induced and an updraft accelerated by wind pressure.

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(812) Describe briefly the difference between heat and temperature.

(813) (*a*) What is the distinction between radiation and conduction? (*b*) Distinguish between a good conductor and a bad conductor.

(814) The specific heat of air is .23751; how many B. T. U. are required to raise 20 lb. of air from zero to 160° F.? Ans. 760.032 B. T. U.

(815) How much heat will be given off by the condensation of 70 lb. of steam having a temperature of 228°? Ans. 66,850 B. T. U.

(816) (*a*) Change 45° C. into F. degrees. (*b*) Change 70° F. into C. degrees. (*c*) Change − 10° C. into F. degrees.

$$\text{Ans.}\begin{cases}(a)\ 113^\circ\ \text{F.}\\(b)\ 21\tfrac{1}{9}^\circ\ \text{C.}\\(c)\ 14^\circ\ \text{F.}\end{cases}$$

(817) (*a*) Describe how you would proceed to find the temperature of hot water flowing through a 3-inch wrought-iron pipe by means of the thermometer shown in Fig. 527, Art. **1394.** (*b*) What precautions must be taken in order to obtain the exact temperature? (*c*) What should the thermometer cups be filled with if made of iron? (*d*) if made of brass?

(818) A vertical vent shaft, 4 sq. ft. in sectional area and 120 ft. high, is filled with hot air having a mean temperature of 100°, the temperature of the atmosphere being zero; what is the difference in weight of the air before and after it is warmed? Ans. 7.4014 lb.

(819) What, in your estimation, is the most accurate method of computing the volume of air delivered by a floor register? Explain clearly how and where you would hold the anemometer.

(820) If the time required to change the direction of a certain current of air through a sharp bend is 1.5 seconds, the force required being 1 lb., and the time required to change the direction through an easier bend having the

same diameter and the air the same velocity is 3 seconds, how much force is saved by the use of the easier bend? Ans. ¾ lb.

(821) What mechanical effects may be observed on heating and ventilating systems by the action of the wind?

(822) Explain, according to the modern theory, the effect of heat upon a body.

(823) Does the transmission of heat through solids depend entirely upon the conducting power of the solid?

(824) A body of air weighing 10 lb., and having a temperature of 10° F., is to be heated by means of 20 lb. of water having a temperature of 200°; what temperature will the air attain, supposing no heat to be lost and that the pressure remains constant? Ans. 179.83°.

(825) How many pounds of steam having a temperature of 228° are required to raise the temperature of 100 lb. of air from zero to 180°? The water of condensation, being allowed to drain off, is of no value for heating the air. Ans. 4.4775 lb.

(826) (*a*) Are alcohol thermometers suitable for ascertaining the temperature of water in heating systems? Give your reasons. (*b*) Are mercury thermometers suitable for determining temperatures lower than − 40° F.? Give reasons.

(827) (*a*) Describe briefly an instrument suitable for finding the quality of saturated steam. (*b*) How should the connection be made to the steam pipe?

(828) Upon what does the rapidity of circulation of any fluid depend?

(829) (*a*) Explain the use of the water gauge in ventilation work. (*b*) Does it indicate the velocity of air in the system?

(830) Explain briefly how enlargements in pipes affect the flow of air through them.

(831) Explain briefly the effect of wind on the draft of square, open-top chimneys if (*a*) the wind blows horizon-

tally; (*b*) if it blows upwards at an angle of 45°; (*c*) if it blows downwards at an angle of 45°.

(832) How do you account for the fact that water, under atmospheric pressure, can not be heated to a higher temperature than 212° F.?

(833) Would a polished copper, or brass, or even a polished nickel-plated cast-iron radiator be suitable for warming buildings? Give your reasons.

(834) How many B. T. U. are required to convert 20 pounds of ice having a temperature of 32° F. into steam at atmospheric pressure, providing that no heat is lost during the process? Ans. 25,785 B. T. U.

(835) What instruments are employed to measure (*a*) sensible heat? (*b*) latent heat?

(836) Explain the principle of the wet and dry bulb thermometer as employed to find the humidity of the air.

(837) The increase of water in the condenser of a separating calorimeter within a certain time is 3.5 lb., and the separator gains in the same time .75 lb. of water; what is the quality of the steam? Ans. 82.35 per cent.

(838) The operative height of the descending column of water in a heating apparatus is 50 feet; the temperature of the ascending column is 210°, and of the descending column, 170°; what is the total motive force which causes the water to circulate? Ans. .3350 lb. per sq. in.

(839) Describe the operation of a differential air gauge, and explain why very light pressures are so noticeable with this gauge.

(840) What is the effect of a dead end on a pipe through which air is compelled to flow?

(841) Are there any objections to warming laundry drying rooms without ventilating them? If so, state them.

(842) Describe the difference between *sensible* and *latent* heat.

(843) (*a*) Water is a poor conductor of heat; explain, then, how it can be rapidly heated throughout its mass

(*b*) Can we uniformly heat the water in a deep open vessel by applying a blowpipe flame to the surface of the water? Give your reasons.

(844) If 5 pounds of steam at atmospheric pressure are discharged into a barrel containing 200 pounds of water at 40°, what will be the final temperature?

Ans. 67.75°, nearly.

(845) (*a*) Why are liquids used in thermometers in preference to solids or gases? (*b*) What liquids are used, and state what class of thermometers they are respectively used for?

(846) Suppose that variations of temperature are too slight to be detected by common thermometers; what instrument may be employed to more accurately find the temperatures? Explain its action.

(847) A current of hot air having a temperature of 140° and a volume of 300 cubic feet per minute is cooled to 60° by passing through a room; what amount of heat is given off per minute? Ans. 377.3657 B. T. U.

(848) What would be the theoretical velocity of the hot air and chimney gases having an average temperature of 300° in a chimney 90 ft. high, the atmospheric temperature being 20°? Ans. 58.11 ft. per sec.

(849) Describe the construction and operation of the differential draft gauge.

(850) Give a sketch showing the contracted vein and state how the flow of air is affected by it.

(851) (*a*) Explain the difference between an automatic induction and automatic eduction cowl. (*b*) How can the cowl shown in Fig. 575, Art. **1469,** be converted into an induction cowl?

(852) (*a*) How is heat measured? (*b*) Describe the unit of measurement. (*c*) How much heat is required to raise 6 lb. of water from 50° to 60° F.?

(853) If 100 cu. ft. of air having a temperature of 0° F.

enter a hot-air furnace, what will be its volume if delivered at a temperature of 160° F.? Ans. 134.8 cu. ft., nearly.

(854) What is the relative humidity when the temperature of the atmosphere is 75° and the dew point is found to be 35°? • Ans. 24.07%.

(855) Suppose that we fill a clean dry glass jar with saturated air having a temperature of 80°, and then place the jar in a room having a temperature of 70°; what deposition will be observed in the jar?

(856) Explain briefly the use of pyrometers. Describe the action of metallic pyrometers.

(857) What is the weight of 100 cu. ft. of air at a temperature of 300°, the pressure being 14.7 lb. per sq. in.? Ans. 5.226 lb.

(858) (*a*) What instrument is used for measuring the velocity of air? (*b*) Describe its action briefly.

(859) At what part of a room should the hygrometer be applied when finding the dew point of the air with a view to computing its humidity? Give your reasons.

(860) Give a sketch showing how the evil effects of the contracted vein may be overcome.

(861) (*a*) How do you account for the fact that by pouring ether on the muslin-covered bulb of a Daniell's hygrometer the other bulb is reduced in temperature? (*b*) Explain how the dew point is obtained.

(862) (*a*) Briefly describe the radiation of heat. (*b*) The temperature of a certain body at a distance of 4 ft. from the source of heat is 500°; what will the temperature be at a distance of 10 ft.? Ans. 80°.

(863) A heating apparatus contains 560 cu. ft. of water at 46° F.; how much will the water expand if the temperature is raised to 200°? Ans. 21.7784 cu. ft.

(864) How many B. T. U. are required to superheat 100 lb. of steam 10°? Ans. 480.5 B. T. U.

(865) (*a*) What is absolute temperature? (*b*) Why do

we make the inference that is involved in determining the absolute temperature?

(866) Suppose that it is desired to obtain the highest and the lowest temperatures that will occur in a given room within a given time, (*a*) what class of thermometers should be employed? (*b*) Explain their action.

(867) How much heat will be required to warm 1,000 cu. ft. of air to a temperature of 160°, the temperature out of doors being 0°? Ans. 3,281.438 B. T. U.

(868) Suppose that we take the anemometer, Fig. 543, Art. **1435,** just as it reads, and hold it in an air-current for two minutes, and suppose that the dial then records 3078; what is the velocity of the current per second?
Ans. 8 ft. per sec.

(869) How do velocity, length of the pipe, and the nature of the rubbing surface affect the skin friction?

(870) A faulty system of distributing air is shown in plan in the accompanying Fig. 9. Draw to a scale of twice the size of this figure the method you would adopt to split

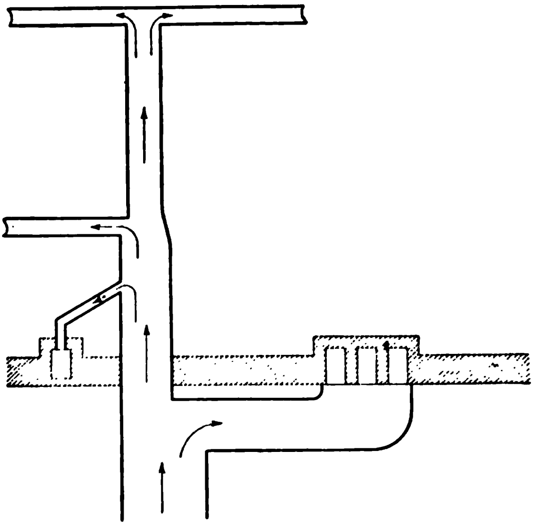

FIG. 9.

the air-currents and give them, not only less resistance, but also a more uniform distribution to all the flues. The arrows show the direction of the currents.

(871) In what form does water vapor exist in the air?

(872) Upon what does the efficiency of a hot-air drying apparatus chiefly depend?

(873) (*a*) Mention some of the evil effects of continued breathing of very dry air. (*b*) About what percentage of moisture should be present in air for breathing purposes?

(874) How many B. T. U. will be required to change 20 lb. of boiling water at 80 lb. absolute pressure into steam of the same pressure? Ans. 17,902.160 B. T. U.

(875) What absolute temperatures correspond to (*a*) 75° F.? (*b*) – 20° C.?

$$\text{Ans.}\begin{cases}(a)\ 535^\circ\text{ F.}\\(b)\ 253\tfrac{1}{3}^\circ\text{ C.}\end{cases}$$

(876) Suppose that it is desired to keep a complete and continuous record of temperature variations in a given room, (*a*) what instrument may be employed? (*b*) Explain its action.

(877) What will be the volume of 1,000 cu. ft. of air having a temperature of 160° when it is cooled to 0°?

Ans. 741.93 cu. ft., nearly.

(878) Explain briefly, with sketch, how the velocity of air under pressure can be approximately obtained.

(879) When it is necessary to change the direction of an air-current, what particular point should be considered in order to form the least possible resistance to the current? Give reasons.

(880) What shape of pipe is best adapted to convey air, when there are no restrictions as to space?

(881) What is understood by humidity of the air?

(882) How do you account for the fact that a highly polished silver vessel, subject to radiant heat, requires a much longer time to heat than a similar vessel made of cast iron?

PRINCIPLES OF HEATING AND VENTILATION.

(ARTS. 1486–1617.)

EXAMINATION QUESTIONS.

(883) How does pressure affect the ignition of an inflammable compound?

(884) In designing a coal bin to contain 25 tons of anthracite coal (stove size), the length of the bin is 18 feet, and its depth is 6 feet; what should be its smallest width, assuming that the shape of the bin is a parallelopipedon?

Ans. 8 feet 4 inches.

(885) (*a*) Distinguish between plain and extended surfaces. (*b*) Are "extended surfaces" of any value in heating water by steam? Give your reasons. (*c*) Under what conditions, and why, are extended surfaces employed to advantage in heating buildings?

(886) Describe the principle of operation of the "positive circulating" radiator, and state why it is called *positive.*

(887) If the velocity of the air which flows through between the pipes of the "heater" shown in Fig. 602, Art. **1552,** is 20 feet a second, and the amount of heating surface in the heater is 3,000 square feet, how much heat would the heater give off to the air, supposing that the original temperature of the air is 60°, and the average temperature of the heater is 210°?

Ans. 4,050,000 B. T. U. per hour.

(888) The amount of heat lost through the walls, etc., and by ventilation, of an audience room is 1,000,000 B. T. U. per hour. An audience of 1,000 adults, and 250 incandescent gas lamps, 50 c. p. each, together give off

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heat which tends to raise the temperature of the room. How many B. T. U. should the heating system transmit to the building, in order to maintain a uniform temperature when the audience is present and the lights burning?

Ans. 100,000 B. T. U. per hour.

(889) What is the direct duty of an automatic temperature regulator when used in connection with (*a*) hot-air furnaces? (*b*) indirect steam heating? (*c*) direct steam heating?

(890) What are the principal points to be considered in selecting the location of inlet and outlet orifices for the heating and ventilation of a room by the indirect process (forced draft)?

(891) A hot-air flue is 1 square foot in sectional area, and the velocity of the air in the flue is 7 feet a second; what diameter of opening of a round register is required to ensure a velocity of 4 feet per second for the air as it enters the room?

Ans. 22 inches, nearly.

(892) Distinguish between an "element," a "chemical compound," and a "mixture." Give one example of each.

(893) Upon what does the rate of combustion of any given substance chiefly depend?

(894) Describe the most positive and most simple form of a pipe coil you can think of, the coil to be set against a wall, and not to exceed 20 feet long or 6 pipes deep.

(895) Briefly describe the construction and operation of a disk fan. Which part of the vane delivers most air, and why?

(896) A vertical 1-inch tube 6 feet long has its top end closed with a cap, its lower end being screwed into a **T** on a horizontal steam pipe. How would you arrange this tube so that the steam will circulate freely through it?

(897) A certain building requires a supply of heat amounting to 5,000,000 B. T. U. per hour to maintain a temperature of 70° when the outer air is zero. The heat is to be obtained from steam having a temperature of 220°,

and the air to be heated is taken from the outer atmosphere. The heating surfaces will be concentrated in the form of a vertical tube heater, as shown in Fig. 602, Art. **1552,** and the velocity of the air through the heater will be 14 feet per second. How many feet of 1-inch tubes will be required for the heater? Consider 3 feet of 1-inch pipe equal to 1 square foot of surface. Ans. 9,090 feet of pipe.

(898) The loss of heat by conduction from a certain building, which is heated by indirect radiation only, is 275,000 heat units per hour. The temperature of the fresh hot air may be taken as 120°, and the rooms are to be maintained at 70°; what should be the volume of the hot-air supply? Ans. 319,000 cubic feet per hour.

(899) Describe briefly the operation of a thermostat which depends upon vapor pressure for its action.

(900) Give a sketch of a room in section, showing how you would arrange the hot-air inlet and foul-air outlet flues on opposite sides of the room. Provide for summer ventilation.

(901) (*a*) What is a non-conductor? (*b*) Is air a good conductor of heat? (*c*) In the employment of an air space as a non-conductor of heat, what must be considered?

(902) Explain briefly what you understand by "chemical combination."

(903) (*a*) Does combustion take place in the heart of a lump of coal, or on the surface? Give reasons for your reply. (*b*) Distinguish between combustion and explosion.

(904) (*a*) Explain the effect of intense heat upon cast-iron grate bars. (*b*) What should be the size of the air spaces between grate bars (1) for anthracite coal; (2) for bituminous coal? (*c*) What class of grate bars is commonly used when the rate of combustion is very high? Give reasons for your replies.

(905) In connecting the outlets of two fans to the same airway, what must be considered? What is liable to happen?

(906) Describe two common forms of indirect extended-surface radiators.

(907) Compute, by Baldwin's rule, the amount of direct radiation required to maintain a temperature of 70° in the room *A*, Fig. 605, Art. **1562,** changing the dimensions (20 feet and 25 feet) to 30 and 35 feet, respectively; the sizes of the windows, height of ceilings, and all other conditions will remain the same as those marked in the figure. Divide the entire radiation into the radiators *a* and *b*.

Ans. { 66 sq. ft. heating surface in *a*.
33 sq. ft. heating surface in *b*.

(908) A certain building requires 319,000 cubic feet of air per hour, for heating and ventilation. The amount of heat lost from the rooms by conduction is 275,000 heat units per hour, and the rooms must be maintained at a temperature of 70°; what must be the temperature of the fresh-air supply on entering the room? Ans. 120°.

(909) How is the combustion of fuel in a small furnace controlled by the pressure of the vapor in the thermostat shown in Fig. 615, Art. **1606**?

(910) How is the general circulation of air within a room affected by windows and cold walls? Explain where you would set a radiator to heat the room shown in Fig. 611, Art. **1587.**

(911) Mineral wool and glass are both composed of the same materials; which is the better non-conductor? How do you account for it?

(912) Explain briefly what you understand by "atomic weight," and state how it is employed in chemical symbols.

(913) A variety of coal has the following composition:

Carbon	77.0 parts.
Hydrogen	5.0 parts.
Oxygen	3.5 parts.
Nitrogen	1.5 parts.
Ash	13.0 parts.
	100.0 parts.

How many B. T. U. will be produced by the combustion of 75 pounds of this coal? Ans. 1,069,875 B. T. U.

(914) Describe briefly the advantages of a good shaking grate over the ordinary straight, rigid grate bars.

(915) Suppose that each square foot of heating surface of a given radiator emits $3\frac{1}{2}$ B. T. U. per hour for each degree of difference in temperature of the steam and cold air, when the air moves at 180 feet per minute; what will be the rate of emission if the velocity is increased to 560 per minute? Ans. 6 B. T. U., nearly.

(916) Describe briefly the construction of a Detroit loop radiator, and explain how steam circulates through it; also, how air is extracted from a steam radiator composed of such loops.

(917) Is it safe practice to proportion radiation to the cubical contents of rooms? Give your reasons.

(918) Describe the direct, direct-indirect, and indirect methods of house heating. How and where are the heating surfaces located?

(919) It is required to move a quantity of air amounting to 15,000 cubic feet per minute, at a pressure of .2 inch of water. (*a*) What will be the amount of heat required to accomplish the work by means of a vertical flue 65 feet high, the atmosphere being at zero? (*b*) What will be the amount of heat required to accomplish the work by means of a good fan, the conversion of heat into power being theoretically perfect?

Ans. $\begin{cases} (a)\ 30{,}762 \text{ B. T. U.} \\ (b)\ 20 \text{ B. T. U., nearly.} \end{cases}$

(920) Should hot air enter rooms through floor inlets? Give your reasons and state any objections you can find to this method of hot-air inlet.

(921) What are the principal points to be considered in selecting and applying non-conductors to steam pipes?

(922) (*a*) Is ordinary atmospheric air an element, a chemical combination, or a mixture? Give reasons for your

answers. (*b*) Roughly speaking, what is the composition of air?

(923) The heat of combustion of a pound of a certain kind of coal is 14,265 B. T. U.; how many pounds of water at 212° F. can be evaporated by 23 pounds of this fuel?
Ans. 339.7 pounds, nearly.

(924) What draft pressure (in inches of water column) will be given by a chimney 95 feet high, the temperature of the atmosphere being 65°, and of the hot gases in the chimney 250°? The area of the grate is 12 square feet, and the coal is burned at the rate of 8 pounds per square foot per hour.
Ans. .3 inch, nearly.

(925) (*a*) What part of a radiator or coil emits most heat to the air in a room? Give your reasons. (*b*) Is a coil arranged with the pipes vertically over one another as efficient as one having the pipes arranged horizontally side by side? Give your reasons.

(926) (*a*) Give a sketch showing what you understand by "staggered pipes." (*b*) In a heater composed of 1-inch pipes, screwed into cast-iron bases, explain the advantages of "staggering" the pipes. (*c*) What are such heaters usually employed for, and how is the air-current usually obtained?

(927) It is found by Baldwin's rule that three rooms, A, B, and C, can be conveniently warmed by three direct radiators (one in each room) having areas of 80 square feet, 60 square feet, and 48 square feet, respectively. (*a*) If these direct radiators should be taken out and be replaced by direct-indirect, how many square feet of such radiation would be required in each room? (*b*) If indirect radiation should be employed instead of direct radiation, how large should the radiator be for each room?

(928) What are the chief objections to the old forms of low down open grates?

(929) Explain the use and operation of (*a*) the steam jet furnace blower; (*b*) the steam jet chimney, or vent shaft, blower.

(930) Is it good practice to run hot-air flues up inside the exposed outer walls of a building? State your reasons.

(931) Mention three general ways in which the temperature of a room may be regulated by controlling the emission of heat from direct steam radiators.

(932) (*a*) What part does nitrogen take in the combustion of fuel? (*b*) What constitutes the products of combustion of carbon, and of hydrogen?

(933) If the volume of a pound of ordinary air at atmospheric pressure is about 13.5 cubic feet, about how many cubic feet of air are required to completely burn 35 pounds of coal, if ordinary natural draft is employed?

Ans. 11,340 cubic feet, nearly.

(934) (*a*) Explain briefly how the air in a room is heated by a radiator placed within it. (*b*) How do air-currents affect the efficiency of a radiator or other hot body employed for warming the air in a building? Give reasons.

(935) What objection is common to all box coils as regards the efficiency of their heating surfaces?

(936) Describe briefly the process of heating a room by direct-indirect radiation.

(937) (*a*) Explain how heat escapes from buildings whose doors and windows are all closed. (*b*) How does "exposure" affect the several rooms of a building as regards heat?

(938) Explain what connections you would make to oil or gas stoves which are to be used for warming rooms.

(939) Describe briefly the construction of a centrifugal fan, and state how the air is caused to flow from it.

(940) Suppose you are called upon to heat a factory with 1-inch pipe coils. The air in the factory is constantly in a state of agitation by belting and machinery in motion. The walls are fitted with work benches which butt close to them. Where would you run the heating coils? Give your reasons.

(941) How is the emission of heat from a hot-water radiator controlled?

(942) (*a*) How many pounds of air are required for the complete combustion of 21 pounds of carbon? (*b*) If the carbon is burned to CO, instead of CO_2, how much air is required?

Ans. (*a*) 243.6 pounds.
(*b*) 121.8 pounds.

(943) A hot-water boiler is consuming coal at the rate of 4 pounds per hour per square foot of grate surface. A low-pressure steam boiler is consuming coal at the rate of 8 pounds per hour per square foot of grate surface, and a steam boiler used for power purposes is consuming coal at the rate of 20 pounds per hour per square foot of grate surface. How many cubic feet of air at 62° F. are required to burn a ton of coal in each?

Ans. Hot-water boiler, 609,700 cubic feet.
Steam boiler, 530,900 cubic feet.
Power boiler, 341,660 cubic feet.

(944) (*a*) What do you understand by the "coefficient of heat transmission," as applied to radiators? (*b*) How does the condition of the heating surfaces affect the emission of heat from radiators and other hot bodies?

(945) (*a*) Describe the construction of a flue radiator. (*b*) Explain how the hot air is disengaged from between the internal surfaces.

(946) Two rooms, A and B, each require precisely the same amount of heat (30,525 B. T. U. per hour) to maintain them at a temperature of 70°. It is proposed to heat the room A with a "direct" radiator composed of a single row of vertical tubes, each 40 inches high. The room B is to be heated with a "direct" radiator composed of a single row of vertical tubes, each 12 inches high. The temperature of the steam in both cases shall be 220°. (*a*) How many square feet of heating surface are required for A? (*b*) How many square feet of heating surface are required for B?

Ans. (*a*) 110 square feet.
(*b*) 80.5 square feet, nearly.

(947) An exceedingly well-built, lathed and plastered, sheathed and weather-boarded wooden wall, having an

area of 875 square feet, allows 6,125 B. T. U. per hour to pass from the air in a room to the outer atmosphere. How many more B. T. U. would be lost per hour if an 8-inch brick wall were used instead, the temperature of the room being 70° and the outer air zero? Ans. 22,050 B. T. U.

(948) Explain a serious defect in cast-iron stoves, as regards the escape of CO. Does the same defect exist to the same extent in wrought-iron or steel stoves?

(949) Distinguish between "exhaust fans" and "pressure fans."

(950) A certain room is to be heated by a flue having a sectional area of 1 square foot. The height of the flue is 10 feet. The outside temperature is – 10°. The average temperature of the air in the flue is 115°. How many cubic feet of air will flow into the room by natural draft in one hour, the conditions being those referred to in Table 66, Art. **1594**? Ans. 23,040 cubic ft.

(951) How may the temperature of a room be controlled when the room is heated by indirect radiation alone?

(952) (*a*) How many cubic feet of air at atmospheric pressure are required to completely burn 135 pounds of carbon? Ans. 20,520 cu. ft.

(*b*) Name the products of the combustion?

(953) Three tons of "pea coal" and 5 tons of "stove coal" are about to be delivered at the coal bin for a steam boiler (pea coal is, say, about $\frac{1}{4}$ of a cubic inch in volume, and stove coal $1\frac{1}{2}$ cubic inches or more). What would you advise as regards the storage and use of the coal, in order that it may be consumed to the best possible advantage?

(954) Three cast-iron radiators, A, B, and C, each having 100 square feet of heating surface, are connected up to heat a room. They all operate under precisely the same conditions, except that A is allowed to remain plain (new); B is covered with two coats of rough bronzing, and C is covered with one coat of glossy white paint. The amount of heat emitted from A is 15,000 B. T. U. per hour. (*a*)

How much heat will be emitted from B in one hour? (*b*) How much from C in the same time?

Ans. $\begin{cases} (a) \text{ 15,900 B. T. U.} \\ (b) \text{ 13,500 B. T. U.} \end{cases}$

(955) (*a*) Describe, with sketch if necessary, the kind of a pipe coil you would place against a straight brick wall, two 6-pipe manifolds to be used in the construction. (*b*) How would expansion and contraction be provided for? (*c*) State how you would secure the coils to the wall.

(956) A certain room requires 31,875 B. T. U. per hour to maintain its temperature at 70°. An extended-surface indirect radiator having a good hot-air flue 5 feet high will be used to warm the room. The temperature of the steam will be 220°. (*a*) How many square feet of radiation will be required? (*b*) If the flue were 35 feet high, instead of 5 feet high, how many square feet of the same class of radiation would be required to accomplish the same results?

Ans. $\begin{cases} (a) \text{ 125 square feet.} \\ (b) \text{ 80 square feet, nearly.} \end{cases}$

(957) (*a*) When a building has a northerly exposure and is subject to strong winds, what allowance should be made on the amount of radiation? (*b*) When a building is heated occasionally for a day only, and is allowed to cool off for intervals of a few days, how much allowance should be made on the amount of radiation required to maintain the room at a constant temperature?

(958) Describe some of the evil effects of having hot air near the ceiling and cold air on the floor.

(959) Should the outlet of a fan extend radially or tangentially from the body? Also, should the casing be concentric with the wheel?

(960) (*a*) What is the maximum velocity with which hot air should enter a room? Give reasons. (*b*) How is this accomplished if the velocity in the duct is much higher?

(961) Explain the use and advantages of "mixing valves" in heating and ventilation work. Where should they be operated from?

(962) The composition of a certain fuel is shown by symbols, as follows :

C	82 parts.
H	6 parts.
O	7 parts.

The ash remaining after combustion is 5 parts. How many cubic feet of air are required to completely burn 121 pounds of this fuel ? Ans. 17,392 cubic feet.

STEAM HEATING.

(ARTS. 1618–1764.)

EXAMINATION QUESTIONS.

(963) (*a*) Describe briefly what you understand by the circulation in a steam boiler. (*b*) State the prime causes of this circulation.

(964) Explain the use of manholes and handholes in steam boilers, and describe how the manhole fittings should be made so as not to weaken the shell.

(965) What are the principal advantages of steam boilers similar to that shown in Fig. 647, Art. **1649,** as regards (*a*) cleaning the flues ? (*b*) the circulation of the water ? (*c*) enlarging the boiler ?

(966) Explain briefly how a sulphate of lime scale may be prevented from forming in a steam boiler by the use of chemicals.

(967) Describe briefly the operation of a pop safety valve.

(968) It is desired to lift the water of condensation 10 feet in order to return it to a low-pressure steam boiler by means of a steam loop. The maximum difference in pressure at the boiler and at the foot of the loop is 2 pounds per square inch. The proportion of steam to water in the riser being 3 to 1, how high must the riser extend above the water-level of the boiler ? Ans. 10 ft., nearly.

(969) Explain, with sketch if necessary, how the expansion of steam pipes may be compensated for by the use of spring pieces.

(970) Describe the drop supply system of steam heating.

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(971) What diameter of low-pressure steam main is required to supply direct radiators having a total heating surface of 4,900 square feet ? Ans. 8-inch pipe, nearly.

(972) Briefly explain what is liable to happen when the waterways of a steam boiler are so obstructed that steam can not freely escape from them.

(973) Describe a boiler staybolt, and mention the conditions under which such bolts may be used.

(974) Describe the difference between fire-tube and water-tube boilers.

(975) Describe a cast-iron drop-tube boiler, and explain how you would empty the tubes of such a boiler to prevent their being frozen and burst during cold weather, when the boiler is not in use.

(976) Describe briefly an apparatus suitable for intercepting scale-forming compounds of lime and magnesia before the feed-water enters a steam boiler.

(977) Would you use a stop-valve for shutting off a safety valve for repairs ? If so, where would you attach the valve ?

(978) Describe a siphon trap, and state the minimum depth of the seal of such a trap if the pressure on one side is 5 pounds and on the other side 2 pounds.

Ans. 7 ft. 3¾ inches, nearly.

(979) Describe a swivel connection used for taking up expansion of steam pipes.

(980) Describe how steam mains should be run and graded. What pitch is usually considered sufficient in a main where the water flows with the steam ?

(981) Mention a few of the most important points which must be considered in piping buildings for low-pressure steam heating.

(982) Mention a few of the main objects of circulation in a steam boiler, and name some mechanical contrivances which are employed to aid circulation.

(983) (*a*) Describe a through stayrod, and explain its

use. How are its ends made steam-tight? (*b*) Are they suitable for long boiler shells? Give your reasons.

(984) (*a*) Describe the general construction of a return-tubular boiler. (*b*) How is it usually supported? (*c*) Which is the most effective part of the heating surfaces of such a boiler?

(985) Distinguish between a boiler horsepower and the horsepower of an engine.

(986) Distinguish between uniform corrosion, pitting, and grooving, as these terms are understood in boiler work.

(987) Describe and give the name of an appliance for attracting the attention of the engineer when the boiler water-line is either too high or too low.

(988) Describe briefly the operation of a bucket steam trap.

(989) (*a*) Explain the duty of a return pipe in a steam-heating apparatus. (*b*) What advantages has the return-pipe system over that which discharges the water of condensation from the heating system?

(990) Give a sketch of a steam main and a return main under it. Both mains are to be run such a long distance that the extreme end of the steam main will be below the water-line in the returns if the main is graded continuously in the ordinary manner. Give the names and describe the uses of the different parts of the piping.

(991) What must be considered in running steam pipes through floors and walls of combustible material? How is the difficulty overcome?

(992) What kind of drop-tube is best adapted for hanging in the furnace of a steam boiler, if the hot gases flow up all around the tube and heat it uniformly all over its outer surface? Give your reasons.

(993) (*a*) If a boiler shell is too long to admit of the use of through stayrods, what kind of stays should be employed to brace the flat ends? (*b*) What is the greatest angle they should make with the shell?

(994) Describe briefly the locomotive type of steam boiler.

(995) How many pounds of steam must a boiler generate per hour to properly supply a 10-horsepower steam engine of ordinary construction (without automatic cut-off), the steam pressure being 70 pounds by the gauge ?

Ans. About 300 lb.

(996) Does fire-tube heating surface or water-tube heating surface in steam-boiler construction suffer most loss of efficiency by being neglected ? Give your reasons.

(997) Explain the use of fusible plugs, and state where they are commonly attached to boilers.

(998) Briefly describe the general principles of an expansion steam trap, and state any objections you may see in them.

(999) Is the steam pressure in the radiators always equal to the boiler pressure ? Give your reasons.

(1000) Where should one-pipe riser connections be taken from steam mains ? Give your reasons.

(1001) Briefly describe the exhaust system of steam heating, and mention how the water of condensation may be returned to the boilers.

(1002) (*a*) What is a baffle plate ? Describe its use inside a boiler, and mention a class of boilers in which baffle plates may be used to good advantage. (*b*) Give an instance of how baffle-plates may be employed to advantage in directing the hot gases around a boiler so as to increase the heat-absorbing surface of the boiler to the greatest possible extent.

(1003) What are crown bars ? Describe their use, and mention the class of boilers in which crown bars must be employed.

(1004) Which is the better form of vertical tubular boiler, that shown in Fig. 639 or that shown in Fig. 640 ? Give your reasons.

(1005) How many square feet of heating surface are required to produce 15 horsepower in (*a*) a return-tubular boiler? (*b*) a water-tube boiler? (*c*) a common cast-iron, sectional boiler?

NOTE.—The boilers must make steam easily, even when the flues are ordinarily dirty, and the rate of combustion must be moderate.

Ans. { (*a*) 270 square feet, nearly. (*b*) 180 square feet, nearly. (*c*) 210 square feet, nearly.

(1006) How should brick walls of boiler settings be bound to prevent their distortion by the heat?

(1007) Explain briefly the action of an automatic damper regulator for low-pressure steam-heating boilers, and state how the chains should be regulated.

(1008) Describe briefly the construction and operation of a positive and automatic air vent for steam radiators.

(1009) Mention the principal points which should be considered in constructing steam-heating apparatus, as regards the removal of the water of condensation.

(1010) Show by sketch a common method of radiator connection under a floor to a vertical steam riser.

(1011) Describe, with sketch if necessary, the action of a steam-pump governor, and mention how the return mains may remain full of water when a steam pump is used to return water of condensation to the boilers.

(1012) Describe the use of return pipes in water-tube steam boilers. What would occur if return pipes were not used in their construction?

(1013) Mention the disadvantages of stayed surfaces in steam-boiler work.

(1014) Describe the Babcock and Wilcox boiler, and explain the route taken by the water in circulating within the boiler.

(1015) How many square feet of grate surface should be allowed for 45 H. P. boilers of the following types: (*a*) return tubular? (*b*) water-tube? (*c*) locomotive (stationary)?

Ans. (*a*) 22.5 square feet, nearly.
(*b*) 13.5 square feet, nearly.
(*c*) 18 square feet, nearly.

(1016) What should be considered in building brick boiler settings, regarding that part of the boiler above the water-line?

(1017) Describe briefly the mode of action of a piston damper regulator.

(1018) The exhaust steam pipe from an engine delivers to the atmosphere through an open mouth above the roof, and throws a heavy spray of hot water on the roof and the street, besides making objectionable sounds. What would you do if called upon to prevent the nuisance? Give the name and explain the action of any appliance you might use.

(1019) What happens when slugs of water accumulate in steam pipes? Mention the name of the trouble, and state how the troublesome sounds are produced.

(1020) Show by sketch a common form of radiator connection above a floor to a vertical steam riser.

(1021) Briefly describe the vacuum system of steam heating, and mention its advantages when exhaust steam is employed for heating purposes.

(1022) Mention the most important conditions which affect the transmission of heat from the hot gases in the furnace to the water in a boiler, and state how the rate of transmission varies with variations in the conditions.

(1023) (*a*) Where are the weakest parts of boiler shells? Give your reasons. (*b*) What are the relative strengths of single-lap seams and double-riveted lap-seams, compared with the strength of the boiler shell?

(1024) Describe the Stirling boiler, and explain the use of the four horizontal drums commonly used in its construction.

(1025) Distinguish between "priming" and "foaming" in boilers, and state what causes these troubles.

(1026) What should be considered in building brickwork around boilers as regards binding it to the walls of the building, or a chimney-stack? Give your reasons.

(1027) What must be considered in setting a pump for raising hot condensed water and for forcing it back to the boiler, as regards the vertical height of the suction pipe?

(1028) Describe clearly the principles of action of a steam-pressure reducing valve suitable for maintaining a uniformly low pressure at the outlet, regardless of the fluctuations of the original pressure.

(1029) Describe the one-pipe system of steam heating, and explain how the water of condensation is returned to the boiler.

(1030) Mention the advantages and disadvantages of wet and dry return mains.

(1031) Briefly describe the district system of steam heating, and mention the fittings and appliances necessarily required when such a system is employed. Where are they usually located?

(1032) In what direction should furnace gases flow, as regards the direction of the flow of water in the boiler, so as to utilize the greatest possible amount of the heat in the gases? Give your reasons.

(1033) (*a*) What seams in cylindrical boiler shells are usually double riveted? (*b*) Why is it necessary to double rivet them?

(1034) Briefly describe the construction and operation of a box-coil boiler.

(1035) (*a*) If water containing carbonate of lime is used as feed-water, what is its effect on the boilers? (*b*) If it contains sulphate of lime, what is the effect?

(1036) Describe briefly the operation of a dead-weight safety valve.

(1037) (*a*) Give the name, and describe the action, of an automatic-acting apparatus which will return the condensed water from a low-pressure heating apparatus to a high-pressure boiler. (*b*) State where the apparatus should be set, and give your reasons. (*c*) How does a draft of cold air affect the working of the apparatus ?

(1038) Describe the construction and explain the operation of a steam-radiator valve which is to be operated by means of compressed air from thermostatic apparatus.

(1039) Describe briefly what you understand by the two-pipe system of steam heating.

(1040) The boiler pressure is 5 pounds by the gauge. The pressure at the end of a return pipe is 3½ pounds. How high is the return-pipe water-line above the boiler water-line ? Ans. 3 feet 7½ inches.

(1041) Describe the construction and operation of ordinary steam cooking boxes.

(1042) (*a*) If flue tubes in locomotive and tubular boilers are too short, what is the result, as regards the economical use of the fuel ? (*b*) If the tubes in a water-tube boiler are too long or have too small a diameter, explain what trouble is liable to occur when brisk fires are run.

(1043) (*a*) Is it good practice to have the longitudinal joints of boiler shells, or screwed joints, subject to the action of fire ? (*b*) Where should the longitudinal joints be located, and how should the ends of steel or wrought-iron tubes be secured in high-pressure boiler work ?

(1044) Describe a magazine-feed, drop-flue, cast-iron, sectional steam boiler, and mention the class of work for which it is best adapted.

(1045) (*a*) What is the effect of incrustation in a steam boiler ? (*b*) Mention some of the troubles or dangers which accompany incrustation in boilers. (*c*) Explain the use of a mud drum, and state where it should be attached.

(1046) Describe briefly the operation of a lever safety valve.

(1047) (*a*) Describe the principle of the steam loop. (*b*) Explain the use of the steam loop in steam heating.

(1048) A straight line of 4-inch steam pipe is to be run

300 feet long. Its ends shall butt against iron columns when the pipe is cold. (*a*) Explain how the expansion of this line may be taken up. (*b*) How much allowance should be made for expansion? (*c*) Describe the appliances you would use.

NOTE.—Assume that there is no room to change the direction of the pipe.

(1049) What do you understand by the separate-return system of steam heating? Mention its special advantages, if any.

(1050) What size of pipe is required as a branch from a riser to supply (*a*) an 84-square-foot direct radiator on the one-pipe system? (*b*) an 84-square-foot direct radiator on the two-pipe system? (*c*) a 120-square-foot indirect radiator on the two-pipe system, assuming the steam pressure never to exceed 5 pounds?

(1051) Describe a steam-jacketed kettle for manufacturing purposes, and mention the advantages of heating sugar, candy, glue, etc., by steam.

(1052) (*a*) What kind of surface in boilers is most liable to be distorted by internal pressure? (*b*) How is the distortion of such surface usually prevented?

HOT-WATER HEATING.

(ARTS. 1765–1840.)

EXAMINATION QUESTIONS.

(1053) Describe the difference in principle between draft regulators for steam and draft regulators for hot-water boilers.

(1054) What is the best method of determining the water-levels in (*a*) an open expansion tank? (*b*) a closed expansion tank used for high pressure?

(1055) What are the principal requirements of valves employed in hot-water heating? Explain how they differ from those used in steam heating.

(1056) How and where should branches be taken off hot-water mains to supply indirect radiators which are lower than the mains? Give your reasons.

(1057) What objections, if any, can you observe in the method of supplying radiators with hot water in the manner shown in Fig. 735?

(1058) (*a*) What is the principal object in view when designing a system of pipes for hot-water heating? (*b*) How is it accomplished?

(1059) A certain circuit, composed of 2-inch pipe, contains 10 elbows and 4 tees as resistances. What length should be added to the circuit to represent the resistance by the fittings? Ans. 163 ft. 4 in.

(1060) What size of pipe would you use to supply 220 square feet of indirect radiation placed in the basement of a building? The circuit is about 100 feet long. Allow for a fall in temperature of 20° F.

(1061) The glass exposure of a greenhouse is 800 square feet; the wall exposure is 200 square feet. How many

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B. T. U. or heat are transmitted from the greenhouse to the outer air during zero weather if the inside temperature is 70° F.? The greenhouse is situated in a place exposed to winds. Ans. 51,000 B. T. U. per hour.

(1062) Suppose that an ordinary tubular steam boiler is to be converted into a hot-water heater. (*a*) How may the heat-absorbing surface of the boiler be conveniently increased without enlarging the boiler shell? (*b*) What must be considered in arranging the tubes, as regards the inlet and outlet of the water?

(1063) In connecting up a draft regulator to a hot-water boiler in a building which is piped "single circuit" throughout, what would you provide for maintaining the regulator at a temperature equal to that of the boiler at all times, whether the circuits are open or closed?

(1064) What provision should be made in hot-water radiator valves to prevent the radiator from freezing if the valve is closed?

(1065) Describe the "butterfly" valve, and explain its use in hot-water heating.

(1066) Describe clearly how flow and return branches should be connected to hot-water mains when the building has no special return main.

(1067) (*a*) Distinguish between an open and a closed circuit. (*b*) The accompanying Fig. 10 shows a boiler in

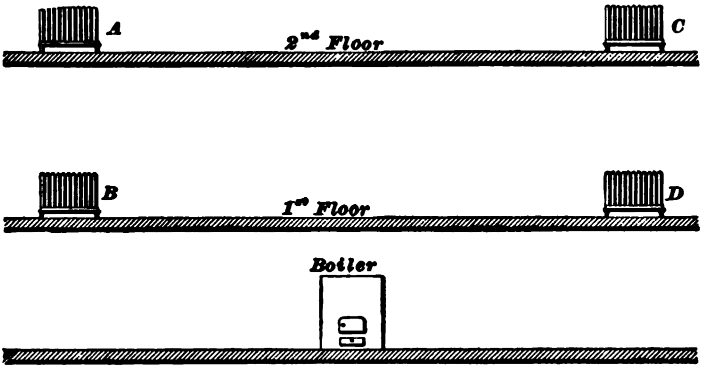

FIG. 10.

the basement, and four radiators *A*, *B*, *C*, and *D* located elsewhere in the building. Show, by a similar sketch, how you would pipe *A* and *B* on the open-circuit system, and *C* and *D* on the closed-circuit system.

(1068) (*a*) A single circuit has flow and return pipes of the same diameter. The velocity in the flow pipe is 1 foot per second; what will be the velocity in the return pipe? (*b*) If the flow pipe has an actual internal diameter of 2 inches and the return pipe 1½ inches, the velocity in the flow pipe being 1 foot per second, what is the velocity in the return pipe? Ans. (*b*) 1.7778 ft. per sec.

(1069) The length of the combined circuits of a hot-water heating apparatus is 800 feet. The radiators supplied by this apparatus are all 10 to 15 feet above the bottom of the boiler. How large should the mains be to supply 650 feet of radiation, allowing for 20° F. fall in temperature at the radiators? Ans. 6 in.

(1070) Suppose that in Fig. 740 the radiators were of the following sizes:

	Riser No. 1.	Riser No. 2.	Riser No. 3.	Riser No. 4.
1st floor..	80 □'	180 □'	76 □'	160 □'
2d floor..		96 □' and 84 □'	104 □'	96 □'
3d floor..	120 □'	84 □'	72 □'	100 □'
4th floor..	36 □'	48 □'		92 □'

The radiator *c* is 60 square feet. Draw to a scale twice the size of the figure, the several lines of pipes shown, and mark the diameters of the different pipes.

(1071) How many square feet of hot-water direct radiation are required to heat an ordinarily well made and moderately exposed greenhouse to 60° F. when the outside temperature is zero? The greenhouse has 2,400 square feet of glass and 600 square feet of exposed wall surface. Ans. 730 sq. ft., nearly.

(1072) Are drop tubes desirable heating surfaces for hot-water boilers? Give your reasons.

(1073) Describe briefly the operation of an automatic damper regulator for hot-water boilers.

(1074) Suppose you were asked to connect a hot-water heating system to the source of supply for the plumbing fixtures; describe clearly how you would arrange the work so as to compensate for expansion and contraction without the use of an expansion tank, and without expanding back into the plumbing system.

(1075) Describe the operation of automatic air vents as commonly employed in hot-water heating.

(1076) The accompanying Fig. 11 is an elevation of a system of hot-water piping placed in a greenhouse. The flow main *a* is run overhead, and the returns are run under the benches, as shown. It was found that after the system was filled with water, and the fire started in the boiler *b*, the pipes would not heat. Steam formed in the boiler and blew to the atmosphere from the expansion tank *c*. The pipes are properly proportioned, and there is ample heating surface under the benches. (*a*) What is the trouble? (*b*) Show, by sketches, if necessary, how you would permanently remedy the defect in the most economical manner and without the use of mechanical contrivances.

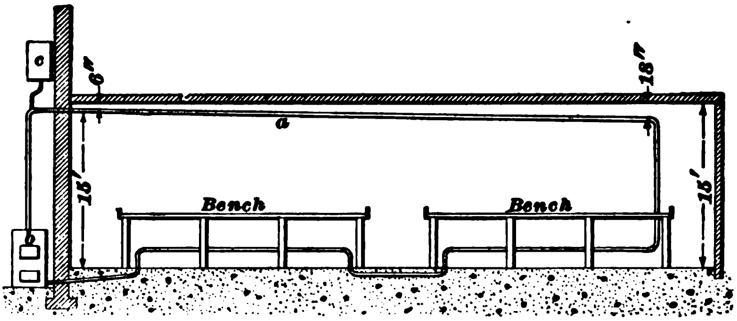

FIG. 11.

(1077) Mention the principal advantages of the closed circuit in hot-water heating systems.

(1078) What is the theoretical velocity of flow through the following circuits: (*a*) 15 feet high, mean temperature of flow 160°, mean temperature of return 140°? (*b*) 80 feet high, mean temperature of flow 200°, mean temperature of return 160°?

Ans. $\begin{cases} (a) \text{ 1.91 ft. per sec.} \\ (b) \text{ 6.03 ft. per sec.} \end{cases}$

(1079) A 4-inch main, forming a circuit of 300 feet, supplies hot water to four 100-square-foot direct radiators situated at a level of 10 feet above the boiler bottom. It is proposed to remove three of these radiators to the third floor and supply them from the same main, along with the radiator which remains on the first floor. How many square feet of additional surface on the third floor will the main conveniently supply? Neglect resistance due to the new risers, and allow for a fall in temperature of 20° F.

Ans. 193 sq. ft.

(1080) (*a*) What are the most advantageous features of the simple-circuit system of hot-water heating? (*b*) What are its disadvantages?

(1081) (*a*) Describe briefly a common form of expansion tank for greenhouse heating when 4-inch pipes are used. (*b*) State where the expansion tank is usually located. (*c*) How are the pipes graded?

(1082) How is the general circulation of water throughout a heating system affected by steam formation in the boiler and ascending main?

(1083) (*a*) What is an "open" expansion tank? (*b*) Explain its use. (*c*) The quantity of water contained in the boiler pipes and radiators of a low-pressure hot-water heating system is 825 U. S. gallons; what space should be provided in the expansion tank between high and low water-levels?

Ans. 5 cu. ft., nearly.

(1084) Why must hot-water radiator sections be joined top and bottom?

(1085) (*a*) What should be considered regarding the weight of the stem and float of an automatic air vent as regards the pressure of the water in the system? (*b*) The stems of the air vents in the lower floors of a tall building seem to stick to the seats, while those on the upper floors operate perfectly; how would you account for it?

(1086) What do you understand by circulation of hot water in gravity-circulating apparatus?

(1087) What do you understand by the one-pipe system in hot-water heating?

(1088) The velocity of water in a circuit which supplies a certain radiator is 1 foot per second. The fall in temperature at the radiator is 40° F. If changes are made which will furnish a velocity of 1 foot 9 inches per second, what will be the fall in temperature at the radiator, the rate of emission of heat from the radiator being the same?

Ans. 22.86° F., nearly.

(1089) What should be the respective sizes of the risers to properly supply (*a*) 100 square feet of direct radiation on first floor? (*b*) 60 square feet on second floor? (*c*) 50 square feet on fourth floor? Use separate risers, and allow for a fall in temperature of 20° F.

(1090) Describe the advantages of hot water as a medium for heating greenhouses.

(1091) (*a*) How are spigot and socket joints in greenhouse heating pipes usually made? (*b*) What objection is there to lead-calked joints for this work?

(1092) What are the characteristic features of boilers and heating systems which contain a small volume of water, and those which contain a large volume?

(1093) (*a*) What is a closed expansion tank? (*b*) Explain its use. (*c*) What must be considered in fitting it up as regards safety?

(1094) In using hot-water coils or radiators for indirect heating, what precaution would you take to guard against the effects of frost?

(1095) (*a*) Explain how it is that "air" gathers in the highest points of a hot-water heating system. (*b*) When does the air cease to accumulate in these points?

(1096) (*a*) Upon what does the motive force, or "head," which causes circulation of water in a gravity-circulating system depend? (*b*) How is it affected by the height of the circuit, assuming the radiator to be located at the highest point?

(1097) In proportioning radiation which is to be supplied by the one-pipe system, what must be considered, and how allowed for?

(1098) It is found that a 2-inch pipe is the proper size to supply a radiator on the first floor of an ordinary building; what size of pipe will be sufficient to give equally good results in supplying the same radiator on the fourth floor, under the same ordinary conditions?

(1099) What is about the practical limit to the height of (*a*) ¾-inch risers? (*b*) 1-inch risers? (*c*) 2-inch risers? Explain why this limit occurs.

(1100) Briefly describe the process of heating a greenhouse with hot water, using cast-iron pipes for heating surface.

(1101) Describe the best process of heating greenhouses with small wrought-iron hot-water pipes.

(1102) What are the characteristic features of a good hot-water boiler as regards (*a*) circulation of water through it? (*b*) arrangement of flues? (*c*) flow and return connections?

(1103) (*a*) Describe briefly the advantages or disadvantages of the open and closed expansion tank systems of warming buildings. (*b*) Which is best adapted for dwelling houses? Give your reasons.

(1104) (*a*) Explain briefly the advantages of bends instead of elbows on hot-water heating work. (*b*) If standard elbows be used, how should the connections to them be arranged so as to furnish the least possible resistance to the flow?

(1105) How, and to what extent, does an air-lock affect the circulation of water in a hot-water heating apparatus?

(1106) If the radiator *b* in Fig. 731 were set in the basement on a level with the boiler, (*a*) would hot water circulate through it? (*b*) What would cause the circulation (if any took place)?

(1107) What do you understand by the equalized system of hot-water distribution? What are its principal advantages?

(1108) A certain hot-water pipe will conveniently supply 84 square feet of direct radiation on the first floor; how many square feet will it supply on the third floor with equally good results? Ans. 142.8 sq. ft.

(1109) What should be the diameters of ordinary radiator connections for direct radiators having (*a*) 24 square feet of heating surface? (*b*) 56 square feet of heating surface? (*c*) 210 square feet of heating surface? Allow for a fall in temperature of 20° F., the radiators being set 10 feet above boiler bottom.

(1110) What do you understand by bottom heat in greenhouse heating? How is it applied?

(1111) Describe the principal points to be considered in arranging small pipes for heating an ordinary greenhouse with low pressure steam.

(1112) What are the principal points to be considered in the construction of a high-pressure hot-water heater as regards (*a*) the material of which the heater should be composed? (*b*) the volume of water contained?

(1113) What must be considered in connecting up expansion tanks, as regards stop-valves and frost?

(1114) What class of fittings is best adapted for joining cast-iron greenhouse heating pipes? Give your reasons.

(1115) How and where should branches to risers be connected to hot-water mains? Give your reasons.

(1116) Describe (*a*) a simple circuit; (*b*) a compound circuit.

FURNACE HEATING.

(ARTS. 1841-1906.)

EXAMINATION QUESTIONS.

(1117) Compare the furnaces shown in Figs. 746 and 747, and state the advantage of either over the other.

(1118) What are the principal advantages of a hot-air furnace similar to that shown in Figs. 752 and 753 ?

(1119) What is a sand ring ? Explain its use.

(1120) Are cup joints filled with sand or furnace cement desirable for furnace construction ? Give your reasons.

(1121) Why is it not good practice to feed coal to a furnace fire through a magazine ?

(1122) Briefly describe the construction of a cold-air pit for a portable setting, the cold-air box being located under the cellar floor.

(1123) The aggregate sectional area of the hot-air pipes is 500 square inches; what should be the minimum sectional area of cold-air box used ? Ans. 334 square inches, nearly.

(1124) (*a*) What is commonly employed for the purpose of causing an equal or proper distribution of hot air to the several leaders on a furnace-heating job ? (*b*) Describe the construction of one of them, and mention where they are usually located.

(1125) Three rooms, one on the first floor, one on the second floor, and one on the third floor, have precisely the same dimensions, glass and wall areas, and exposures. There are 50 square feet of glass surface and 240 square feet of exposed wall surface in each room, all exposures being very severe. What should be the diameters of the

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hot-air pipes for each room? Allow for a very short leader for the first floor and long leaders for the second and the third floor.

Ans. { First-floor leader, 14½ in. diameter.
Second-floor leader, 13¼ in. diameter.
Third-floor leader, 11⅞ in. diameter.

(1126) The grate surface of a hot-air furnace is 6.5 square feet. How many square feet of heating surface ought the furnace to have in order to obtain good results?

(1127) Describe how the air flows through between the heating surfaces of the furnace shown in Fig. 748, and explain the route by which the hot furnace gases pass to the chimney.

(1128) (*a*) What is a "combination heater," as understood by furnacemen? (*b*) Describe its general construction, and state when it is good practice to use one. Give reasons.

(1129) In selecting a furnace, what points should be considered in connection with the space between the dome of the furnace and the bonnet? Give your reasons.

(1130) How is the purity of the hot-air supply affected by the chimney draft, when the joints of the fire-pot and the combustion chamber are loaded with sand?

(1131) Mention two common methods of regulating the draft in a hot-air furnace, and state any objections you may have to either.

(1132) What is a "cold-air box," as understood by furnacemen? To what point should it be run? Give your reasons.

(1133) What do you understand by an "inside cold-air duct"? Explain its use, and state where the air supply for such ducts should be taken from in ordinary residence work.

(1134) Briefly describe a hot-air register.

(1135) What is the approximate diameter of a hot-air pipe capable of delivering 21,000 cubic feet of air per hour to (*a*) the first floor? (*b*) the second floor? (*c*) the third floor? The temperature of the air will be about 120° F., and the current will be caused by natural draft alone.

Ans. $\begin{cases} (a)\ 16\frac{3}{8} \text{ in.} \\ (b)\ 14\frac{5}{8} \text{ in.} \\ (c)\ 13\frac{3}{8} \text{ in.} \end{cases}$

(1136) If a hot-air furnace is properly constructed, about what should be the highest temperature of the hot gases as they leave the heater, the temperature of the hot air being about 180 degrees F.?

(1137) Explain the proper positions of the dampers in the furnace shown in Fig. 749, (*a*) when the fire is being started; (*b*) when the furnace is in operation and heating the air; (*c*) when the fire is being cleaned.

(1138) Describe a single jacket for a hot-air furnace. Explain its duty, and state how it is usually provided to prevent undue loss of heat.

(1139) Briefly state the advantages and disadvantages of (*a*) fixed grates; (*b*) shaking grates; (*c*) revolving-bar grates.

(1140) Is cast-iron a proper material for fire-pots and combustion chambers of hot-air furnaces? Give your reasons.

(1141) Which is the best location for a furnace, the windward side or the leeward side of a building? Give your reasons.

(1142) What advantages are gained by using glazed earthenware pipe for an underground cold-air box or inlet pipe.

(1143) Give a sketch and explain the action of an automatic controlling valve suitable for the inlets of cold-air boxes.

(1144) Give a sketch of the best form of floor register box you can think of, and explain its advantages over the common form shown in Fig. 769, head-room in the cellar being no object.

(1145) The loss of heat by conduction and radiation through the walls and windows, etc., of a building is estimated at 136,000 B. T. U. per hour. What size of a hot-air furnace is required to heat the building to 70° in zero weather, no definite ventilation system being employed? (*a*) The efficiency of the furnace being 50 per cent., how much coal will be required to heat the building for a period of 24 hours? Assume the calorific power of the coal to be 13,400 B. T. U. (*b*) What size of grate will be required, the rate of combustion being 4 pounds per hour per square foot of grate area? (*c*) How much heating surface will be required in the furnace, ratio of grate to heating surface being 1 to 45?

Ans. { (*a*) 1,056 lb., nearly.
(*b*) 11 sq. ft.
(*c*) 495 sq. ft., nearly.

(1146) In the selection of a hot-air furnace, what are the main points to be considered regarding the arrangement of the heating surfaces?

(1147) Briefly describe the main advantages of the furnace shown in Fig. 751 as regards the transmission of heat from the fuel to the air.

(1148) Describe the construction of a double jacket for a hot-air furnace. Explain its function, and state how it prevents loss of heat.

(1149) Are straight cylindrical or tapered fire-pots best adapted for hot-air furnaces? Give your reasons.

(1150) Explain the use of a direct draft in drop-flue furnace construction.

(1151) Suppose that while digging a furnace pit you discover an earthenware house-drain so laid that it will come directly under the furnace; what would you do?

(1152) (*a*) How would you arrange the cold-air box for a furnace to take air from either of the opposite sides of a building, according to the direction of the wind? (*b*) What are the advantages of the arrangement?

(1153) (*a*) What is a "leader pipe" in hot-air furnace work? (*b*) The leader to a certain room is very long, and it is found that the room supplied by it does not heat properly. The leader is made of bright tin (uncovered) and passes through a cold part of the cellar. How would you increase the supply of heat to this room without taking down or changing the pipe or any other part of the apparatus?

(1154) Are "double-register boxes" desirable? Give your reasons. Describe the best simple method of construction.

(1155) When and under what conditions is it advisable to use two or more hot-air furnaces to heat a building? Give your reasons.

(1156) Mention the principal objections to a portable hot-air furnace which is essentially composed of the following parts: base ring, ash pit, corrugated fire-box, plain cylindrical combustion chamber with domed top, single sheet-iron jacket, direct draft from combustion chamber to chimney.

(1157) It is sometimes found that water gathers in the lowest parts of the drop flues of a hot-air furnace which uses gas as a fuel. (*a*) How would you account for the presence of the water? (*b*) How can it be drained off without affecting the draft of the chimney?

(1158) Describe two common forms of furnace bonnets and state the advantages of each.

(1159) Should the linings of fire-pots in hot-air furnaces be made of firebrick or of cast iron? Give your reasons, and mention the advantages of the lining, if any.

(1160) Mention the most important points to be considered in installing water pans in hot-air furnaces.

(1161) What are the most important points to be considered regarding the location and depth of a furnace pit?

VENTILATION OF BUILDINGS.

(ARTS. 1907-2015.)

EXAMINATION QUESTIONS.

(1162) What kind of dust must be chiefly considered in designing a ventilating system? Give your reasons.

(1163) Mention three ways in which watery vapor affects air.

(1164) How do the incandescent electric light and the open-flame oil lamps or gas burners affect the purity of the air in a closed room?

(1165) (*a*) What is about the proper dew point for an air supply to a ventilating system in the United States? (*b*) If the air is 70° F. in the rooms, what percentage of humidity would this dew point represent?

(1166) What are the common objections to the use of wet and dry filters, respectively, in ventilation work?

(1167) Describe briefly the advantages of the *downward system* of ventilation as applied to large audience rooms.

(1168) How do open stairways in tall buildings affect the ventilation?

(1169) About what should be the velocity of the air in (*a*) the main flue, or duct; (*b*) the wall flues, a fan being used to force the air through them to the different rooms?

(1170) Mention one of the most important points to be considered in ventilating kitchens, and state how the ventilation should be accomplished.

(1171) Define ventilation, and distinguish between ventilation and aeration, as understood by ventilating engineers.

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(1172) What are *bacteria?* Mention the names of the two great classes of bacteria, and describe briefly their peculiar features.

(1173) Explain how humidity affects us during hot weather.

(1174) Ought the volume of the air supply necessary for good ventilation to vary with the condition of the atmosphere? State reasons for reply.

(1175) Describe briefly a simple method of moistening air by means of a spray of water.

(1176) A certain room is found to be badly ventilated. Anemometer tests show that the proper amount of air is constantly passing through it, yet the air tester indicates that there are foul corners. How do you account for the vitiated state of the air?

(1177) Briefly compare the advantages and disadvantages of the *exhaust* and of the *pressure systems* of ventilation, and state which system is best adapted for the ventilation of schools.

(1178) Explain how the *natural-draft system* furnishes poor ventilation at the time when good ventilation is most required.

(1179) Briefly mention the prime requisites of a good duct, or flue, for ventilating purposes.

(1180) Is it necessary to ventilate cellars? Give your reasons, and explain where the foul air should be taken from, and how.

(1181) What does the subject of ventilation include?

(1182) Define *sewer gas*, and describe its general effect upon those who inhale it.

(1183) Explain the chief causes of the failures which have so often been made in attempting to cool large audience rooms during hot weather by the use of wet screens or water sprays.

(1184) Is it practicable to make proper calculations for ventilation, based upon the cubical contents of a room? Give reasons for your reply.

(1185) Explain the *evaporating-pan* method of moistening air for ventilating purposes. How should the pans be fed? Give your reasons.

(1186) Does carbonic acid gas fall down and lie upon the floors of unventilated rooms; or where does it go? Give your reasons.

(1187) Briefly describe the principle of the *aspiration system* of ventilation.

(1188) A close, unventilated room is heated by means of coils running along the front wall under the windows, and it is desired to ventilate this room. (*a*) What are the most important points to be considered in regard to the ventilation of the room? (*b*) How would you proceed to ventilate the room without changing the heating system?

(1189) Describe clearly the *dry-closet system* of heating and ventilating schoolhouses, and explain the insanitary nature of the same.

(1190) What are the advantages and disadvantages of having the partitions in an ordinary framed dwelling arranged so as to form an open communication between cellar and attic? Give your reasons.

(1191) (*a*) What is the primary object of ventilation? (*b*) What is the general effect of bad ventilation upon human beings?

(1192) (*a*) What are the main constituents of ordinary *ground air?* (*b*) Would you expect to find the foulest ground air in dry or in damp cellars? Give your reasons.

(1193) How is the proportion of oxygen in the atmosphere affected by humidity?

(1194) In testing air for vitiation, why is it that the test is usually made for CO_2 only?

(1195) Half a pound of water is required per hour to properly moisten the air supplied to a certain building; steam from jets operating with a pressure of 5 lb., by the gauge, furnishes the moisture. How many jet holes, each $\frac{1}{32}$ inch in diameter, are required? Ans. 13 holes.

(1196) In applying warm air to a room, what are the most important points to be considered in order to obtain a proper diffusion of the heat?

(1197) How and where should steam coils be used for auxiliary service in an aspiration system? State reasons for your reply.

(1198) (*a*) What are the main points to be considered in selecting a fan for ventilating a large building? (*b*) Which is best adapted for the work, a centrifugal or a disk fan? Give reasons for your reply.

(1199) Explain how the dry-closet system of ventilating schoolhouses is a disease breeder of the worst character.

(1200) How should curtains and window shades be hung, so as to allow for summer ventilation?

(1201) What constitutes good ventilation? Describe clearly.

(1202) What is the main difference between underground air and the air above ground?

(1203) How does atmospheric steam affect the density of the air? Is a given volume of damp air heavier than the same volume of dry air, at the same temperature? Give your reasons, and quote an example.

(1204) How is a sample of vitiated air taken by means of the gas-bag? Mention the precautions to be observed.

(1205) Suppose you were called upon to dry damp air by mechanical means, before blowing it into a building, the initial and final temperatures to remain the same. Explain how you would proceed to do this.

(1206) Explain how a coal stove may be used as an auxiliary appliance in an aspirating stack, and state its advantages (if any) over a steam coil for this purpose.

(1207) What are the principal objections to systems of ventilation in which both exhaust and pressure fans are operated? Give reasons for your answer.

(1208) Looking at the problem of the ventilation of buildings from a sanitary standpoint, mention what classes of buildings should receive the most consideration. Classify them and give your reasons.

(1209) What is the chief object in connecting the smoke-pipe from the kitchen range into the aspirating chimney shown in Fig. 788 ?

(1210) Why is it that air which has been already once breathed by men or animals is thus rendered unfit for further respiration ? Explain fully what takes place.

(1211) What are the chief objections to taking a supply of fresh air from the ground level ? State them fully.

(1212) Can the sense of smell be depended upon for determining the amount of vitiation in the air ? Give your reasons.

(1213) Describe briefly the most accurate process you know of determining the amount of CO_2 in air, and state how the measurements are made.

(1214) Describe a wet filter as used for filtering air, and explain how the air is cleansed.

(1215) Given a room 60 feet long, 20 feet wide, and 15 feet high. It is required to blow warm air from one end of the room to the other; should the air be introduced through the end wall, at the floor, at the ceiling, or at a point between floor and ceiling ? Give your reasons.

(1216) What is the use of cowls in ventilation work ? Do they promote the ventilation when fresh air is most needed ?

(1217) In warming and ventilating a building, what provision should be made for the controlling of the temperature of the incoming air, without changing the volume ?

(1218) Mention the main points to be considered in ventilating an ordinary small dwelling.

(1219) Describe clearly, in your own words, how the factory shown in Figs. 796 to 798 is ventilated.

(1220) (*a*) Explain clearly how it is that respiration may be likened to ordinary combustion. (*b*) How much CO_2 is given off by the average adult in 24 hours ?

(1221) How do you account for the fact that the air in a deep well sometimes becomes so deficient in oxygen as to extinguish a lighted candle or lamp which may be lowered into it ?

(1222) What degree of purity in the air is required to constitute good ventilation ? Base your answer upon the amount of CO_2 present per 10,000 parts of air.

(1223) What are the principal points to be considered in preparing air for personal use (*a*) during summer? (*b*) during winter ?

(1224) Describe a dry screen filter for filtering air, and state how many square feet of filtering surface should be exposed to the air in a flue 4 feet wide by 6 feet high.

(1225) How do irregularities in the temperature of the air in a music hall affect the music ?

(1226) Should a damper be placed at the top or the bottom of a large aspirating shaft ? Give your reasons.

(1227) Explain how the arrangement shown in Fig. 787 is operated (*a*) to admit fresh air from the outer atmosphere only; (*b*) to heat the room by local circulation.

(1228) Mention one of the chief difficulties to be found in securing a proper distribution of warm air in the several stories of a dwelling.

(1229) Briefly describe, in your own words, the general arrangement of the ventilating system shown in Figs. 789 to 793.

(1230) (*a*) What do you understand by ***organic impurities*** in the air ? (*b*) Explain their effect upon the human system. (*c*) How can the amount of organic impurities be easily and approximately determined ?

(1231) Should coal be sprinkled with water to keep down the dust while it is being shoveled into a coal bin in the cellar of a dwelling house? Give reasons for your answer.

(1232) How many cubic feet of fresh air should be allowed for each adult person in an audience, so as to ensure a respirable purity of 2 parts of exhaled CO_2 per 10,000 parts of air? Prove the accuracy of your reply.

(1233) Describe briefly, in your own words, the general arrangement of the heating and ventilating system shown by Figs. 794 and 795.

(1234) In Fig. 788 you will notice that one hot-air leader pipe supplies two flues; what provision should be made to prevent the upper register from robbing the lower one?

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